BANANA YIELDS IN RELATION TO NITROGEN AND POTASSIUM COMPOSITION OF LEAVES

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN AGRONOMY AND SOIL SCIENCE

AUGUST 1973

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I. INTRODUCTION

Bananas have been an important food in south-east Asia, the south Pacific and tropical Africa for millenniums, but the fruit did not enter world commerce significantly until about 100 years ago. As demand grew, large areas of land in tropical America were developed for banana cultivation. Total banana export in 1970 was about 5.8 million tons with tropical America accounting for about 90 percent (United States Department of Agriculture, 1972).

Hawaii produced about 3000 tons of bananas in 1972, entirely for domestic consumption (Hawaii Crop and Livestock Reporting Service, 1972). That year the three main varieties of bananas grown commercially and their relative abundances were Bluefield 41%, Chinese 37%, and Brazilian 22%.

Ten new banana varieties have been imported into Hawaii since 1950 in an attempt to provide better disease resistance, production and marketability. These varieties have been listed and briefly described by Hamilton (1971). The most popular, acceptable and widely grown of the recent introductions is Giant Cavendish (Williams Hybrid). It was introduced to Hawaii from Coff's Harbor, New South Wales in 1954 by J. H. Beaumont of the University of Hawaii, and is beginning to replace the Chinese (Dwarf Cavendish) variety (Warner et al., 1973). An advantage of this variety, noted in Australia, is that it is somewhat tolerant of marginal soil conditions, and on relatively poor soil with less than ideal weather conditions it will produce more marketable fruit than the Chinese variety (Hamilton, 1958).

It is not known to what extent research and grower experience gained with Bluefield, Chinese, and Brazilian bananas in Hawaii apply to

Giant Cavendish. Cooperative studies between the Oahu Banana Producers Association and the University of Hawaii, College of Tropical Agriculture, are underway to establish guidelines for management of this banana variety. The work described in this thesis constitutes a part of these studies.

The main problem to be considered is the determination of optimum leaf concentration ranges of nitrogen and potassium or, in other words, the leaf concentrations of these nutrients associated with highest banana yields.

Another problem to be considered in this thesis is the variation of leaf concentrations of nitrogen and potassium in a banana plant. Both leaf to leaf variations and variations within a single leaf were studied. Such information is needed in order to be able to more intelligently sample banana plants and make valid recommendations.

II. REVIEW OF LITERATURE

Giant Cavendish Banana

All bananas bearing edible fruit belong to the genus Musa. The taxonomic position of this genus in the monocotyledonous plants may be understood by referring to Table 1 which was adapted from Champion (1963). Simmonds (1966) has found it convenient to subdivide Musa into sections as presented in Table 2. Of these sections Callimusa and Rhodochlamys are of ornamental interest only. Australimusa includes both Musa textilis which yields Manila hemp and the Fe'i bananas of the Pacific which bear edible fruit. The section Eumusa is the biggest and geographically most widely distributed of the genus. In this section are Musa acuminata and Musa balbisiana. According to Simmonds (1966) a majority of the edible bananas now cultivated have had their origins in these two wild species. Cultivated varieties may be divided into six groups on the basis of ploidy and the contributions made to their origin by the two species. Two groups of clones are derived solely from Musa acuminata, while the remaining four groups are of hybrid origin. Gros Michel, Red and Green Red, and the Cavendish varieties (i.e., Dwarf Cavendish, Giant Cavendish, Robusta, Pisang Masak hijau) constitute one of the former groups.

The Giant Cavendish variety of bananas is known by numerous other names. Principal synonyms are: Giant Chinese, Mon mari (Queensland), Williams Hybrid (New South Wales) and Grande naine (West Indies). It occurs occasionally in any Cavendish-type planting and Simmonds (1966) indicates that existing commercial populations have had separate origins. The clone introduced to Hawaii originated as a mutant in a commercial planting of Dwarf Cavendish near Coff's Harbor, New South

Table 1. The position of the genus Musa in the monocotyledons.[1/]

Order	Families	Subfamily	Genus
Scitaminales	Musaceae	Musoideae	Musa
			Ensette
		Strelitzoideae	Ravenala
			Phenakospermum
			Strelitzia
		Heliconioideae	Heliconia
	Lowiaceae		
	Zingiberaceae		
	Marantaceae		
	Cannaceae		

[1/] After Champion, 1963

Table 2. Conspectus of the banana.[1/]

Genus	Basic Chromosome Number	Section	Number of Species	Uses
Ensete	9	-	7-8	Fiber, Vegetable
Musa	10	Australimusa	5-6	Fiber, Fruit
	10	Callimusa	5-6	Ornamental
	11	Eumusa	9-10	Fruit, Fiber, Vegetable
	11	Rhodochlomys	5-6	Ornamental

[1/] After Simmonds, 1966

Wales (Hamilton, 1958). It is commonly called Williams Hybrid in Hawaii. Since the variety is not a hybrid in the usual sense of that term, it will be referred to as Giant Cavendish here.

General plant and fruiting characteristics of Giant Cavendish have been described by Hamilton (1958). The following is slightly modified from his description. Pseudostems are 7 - 12 feet high, with a considerable amount of red pigmentation. Leaves are longer and wider than Chinese (Dwarf Cavendish) measuring up to 80 inches long and 30 inches wide. Bunches are larger and cylindrical with 9 to 14 hands when well grown. Flower bracts shed more readily than Chinese, and the flowering axis below the bunch tends to be curved rather than straight. Bunches are usually larger and heavier than Chinese and require propping to prevent the stem from breaking. Individual fruits resemble Chinese bananas but tend to be longer, straighter and more uniform in size from top to bottom of the bunch. Because it is taller, Giant Cavendish is less likely to "choke" (impeded bunch emergence related to low temperatures) in winter than the Chinese variety (Simmond, 1966).

Relation Between Leaf Nutrient Concentration and Yield

When the supply of an essential plant nutrient element is severely limited, plant growth and crop yield are affected and deficiency symptoms may appear in leaves, fruit or other plant parts. Visual symptoms of deficiencies of the major elements in the bananas have been described by Murray (1959) and Martin-Prevel and Charpentier (1963). Deficiency symptoms of K and Mg (Turner and Bull, 1970) and P (Lacoenilhe and Godefroy, 1971) have also been considered in more recent papers.

Growth and yield may be affected considerably without deficiency symptoms appearing, when the concentration of an essential nutrient element in the plant falls below the optimum or critical level for that nutrient. Under these circumstances, leaf analysis may be useful for diagnosing malnutrition. Goodall and Gregory (1947) and more recently Chapman (1966) and Bould (1968) have reviewed the methods used and suggested the levels of nutrient elements in the leaves and other parts of many plants which may be related to their performance in the field. Most of this work pertains to temperate and sub-tropical crops.

Hewitt (1955) was among the first to study leaf mineral composition in relation to yield in bananas. He analyzed samples of the third leaf in the succession of leaves from the top of the plant at the time of shooting. Increased yields could be correlated with increased nitrogen content of the leaf and a critical level of 2.60% N was suggested. In further field studies (Hewitt and Osborne, 1962) critical levels of K and P were determined to be about 3.32 and 0.17 - 0.20%, respectively. In the presence of adequate N and P, fruit weight was doubled by application of K fertilizer to plants whose leaves contained less than 2.1% K.

Fertilizer trials with the Giant Cavendish variety have been carried out by Bhangoo et al. (1962) in the Republic of Honduras. Nutrient contents of leaf tissues sampled in the same manner as Hewitt (1955) increased in proportion to the rates of N, P, and K fertilizer application and were positively correlated with banana yields. Critical levels of nutrients were not determined, but it was reported that low yields were obtained with leaf concentrations of 2.56% N, 2.62% K,

and 0.356% P.

Data on the growth and yield of Giant Cavendish bananas receiving different rates of K at various places in Taiwan has been presented and discussed recently in relation to leaf K levels (Ho, 1968, 1969). Leaf K changed with plant age. It was greatest about five to six months after planting. Correlations between yield and leaf K were closest during this period and the critical K level was about 4.75%.

In experiments with Giant Cavendish (Grand naine) bananas conducted by Martin-Prevel et al. (1969) in the Ivory Coast, the last leaf to unfurl was sampled at the time of harvest. This method was developed by Dumas (1958). Critical nutrient levels were 3.1 - 3.3% N, 2.8 - 3.2% K, and 0.19 - 0.22% P.

In Israel, only in the case of K was there an apparent relation between yield responses and nutrient contents of Dwarf Cavendish leaves (Hagin et al., 1964). Brzesowsky and Van Biesen (1962) investigated Lacatan bananas in the Cameroon Republic and found that increased potash dressings were associated with increased mean bunch weight and K concentration in the first fully developed green leaf.

Tables 3 to 5 summarize the literature on leaf nutrient concentrations in relation to plant performance in the field. Published research in this area is somewhat confused. Although data have been collected in many countries and for many varieties of bananas, the published critical values are not generally applicable. Additional knowledge concerning interactions of season and growth stages on leaf mineral concentration is desirable (Martin-Prevel et al., 1969). A better understanding of banana plant development would be helpful also.

Table 3. Relationship between plant condition and leaf N content in dry matter.

Variety	Reference	Location	Leaf Sampling	Leaf Content (%)	Plant Condition
Giant Cavendish	Bhangoo et al. (1962)	Hondurus	3rd at shooting	2.56	low yield
	Martin-Prevel (1969)	Ivory Coast	1st at harvest	3.10-3.30	critical level
Dwarf Cavendish	Bidner-Barhava & Ravikovitch (1958)	Israel	3rd at shooting	2.49	adequate
	Murray (1960)	Trinidad	3rd at shooting	1.50	severely deficient
				2.60	adequate
	Hagin et al. (1964)	Israel	3rd	3.20	deficient
	Martin-Prevel (1969)	Ivory Coast	1st at harvest	3.40-3.60	optimum
				2.50-3.00	deficient
Lacatan	Hewitt (1955)	Jamaica	3rd at shooting	2.60	critical level
	Boland (1960)	Jamaica	2nd at 6-8 months	2.80-3.00	adequate
	Hewitt & Osborne (1962)	Jamaica	3rd at shooting	2.60	critical level
Robusta	Twyford & Coulter (1964)	Windward Islands	4th before shooting	2.90	adequate
	Twyford (1967)	Windward Islands	4th before shooting	2.90	critical level

Table 4. Relationship between plant condition and leaf K content in dry matter.

Variety	Reference	Location	Leaf Sampling	Leaf Content (%)	Plant Condition
Giant Cavendish	Bhangoo et al. (1962)	Hondurus	3rd at shooting	2.62	low yield
				2.86	high yield
	Martin-Prevel et al. (1969)	Ivory Coast	1st at harvest	2.80-3.20	critical level
	Ho (1969)	Taiwan	3rd at 6 months	4.75	critical level
Dwarf Cavendish	Bidner-Barhava & Ravikovitch (1958)	Israel	3rd at shooting	2.00	adequate
	Murray (1960)	Trinidad	3rd at shooting	2.07	severely deficient
				2.74	adequate
	Hagin et al. (1964)	Israel	3rd	3.30	critical level
Lacatan	Boland (1960)	Jamaica	2nd at 6-8 months	3.15-3.32	adequate
	Hewitt & Osborne (1962)	Jamaica	3rd at shooting	3.32	critical level
	Brzesowsky & Van Biesen (1962)	Cameroons	1st	4.71	yield still increasing
Robusta	Twyford & Coulter (1964)	Windward Islands	4th before shooting	3.15	adequate
	Twyford (1967)	Windward Islands	4th before shooting	3.15	critical level
Poyo	Martin-Prevel et al. (1969)	Ivory Coast	1st at harvest	4.20-4.50	insufficient
				4.50-4.80	optimum

Table 5. Relationship between plant condition and leaf P content in dry matter.

Variety	Reference	Location	Leaf Sampling	Leaf Content (%)	Plant Condition
Giant Cavendish	Bhangoo et al. (1962)	Hondurus	3rd at shooting	0.356	low yield
	Martin-Prevel et al. (1969)	Ivory Coast	1st at harvest	0.19-0.22	critical range
Dwarf Cavendish	Bidner-Barhava & Ravikovitch (1958)	Israel	3rd at shooting	0.38-0.64	adequate
	Murray (1960)	Trinidad	3rd at shooting	0.088	severely deficient
				0.196	adequate
	Hagin et al. (1964)	Israel	3rd	0.19	P required
Lacatan	Boland (1960)	Jamaica	2nd at 6-8 months	0.198-0.220	adequate
	Hewitt & Osborne (1962)	Jamaica	3rd at shooting	0.176-0.198	critical range
Robusta	Twyford & Coulter (1964)	Windward Islands	4th before shooting	0.17	adequate
	Twyford (1967)	Windward Islands	4th before shooting	0.128-0.211	critical range
Poyo	Martin-Prevel (1969)	Ivory Coast	1st at harvest	0.27-0.42	optimum

At the present stage of development, critical concentration ranges should be developed for several environmental conditions. Later efforts can be directed toward developing a critical concentration range for a group of environments.

Determination of a Leaf Sampling Method

Leaf sampling is much easier in the case of monocots than in the case of dicots because leaves emerge at fairly regular intervals in the case of the monocots. The newest leaves all grow out of the center of the plant, and it is simple to number the leaves in succession downwards, taking the latest fully opened leaf as the first leaf in the succession. In plantation situations involving large numbers of plants with similar nutritional status, all leaves with the same number will have approximately the same age. A fairly precise system of leaf analysis for practical purposes should thus be possible with bananas.

Hewitt (1955) first investigated which of the leaves of mature banana plants would be the truest indicator of the plant's nutrition. He studied the Lacatan variety in Jamaica. The third leaf consistently contained more nitrogen than other leaves. Leaves progressively lost nitrogen as they became older. Leaf concentrations of K and P were directly related to the age of the leaf. The youngest leaf (leaf No. 1) had the highest levels. Hewitt (1955) decided that leaf No. 3 was the best indicator tissue.

Also working with Lacatan plants, Boland (1959) reported that for the Lacatan variety P and K decreased with leaf age but N increased to a peak, then fell off. Since in most cases the No. 2 leaf contained the highest N concentration, it was sampled in subsequent nutrition

experiments (Boland, 1960). Twyford and Coulter (1962) obtained similar results with Robusta bananas, except that the fourth leaf was found to have the highest N concentration. In a four year study of the Giant Cavendish in Australia in which leaf samples were analyzed every two weeks it was determined that N, P, and K all decrease with advancing leaf age (Turner and Barkus, 1970).

Dumas (1958) suggested that the last expanded leaf (leaf No. 1) be used for sampling purposes, because its physiological development could be more easily defined than previously emerged leaves. Brzesowsky and Van Biesen (1962) and Martin-Prevel et al. (1969) have used this tissue in their nutrition experiments.

Nutrient deficiencies influence the distribution of elements in the leaves of banana plants. Using Dwarf Cavendish in sand cultures, Murray (1960) investigated such deficiencies. When the nitrogen supply was plentiful the highest N concentration was in the fourth leaf, but when nitrogen was in short supply the highest concentration was in the first leaf. Potassium concentration declined little with increasing age of the leaf when K was plentiful. However, there was a rapid decline of K with increasing age in the case of a deficient K supply. In more recent work involving solution cultures of banana plants, Lacoenilhe and Martin-Prevel (1971a, 1971b) also determined that both N and K decrease with leaf age when these elements are deficient. They suggest (1971b) that because K is translocated preferentially to young leaves, they are not the best indicators of K deficiency.

An excess or deficiency of one nutrient may affect the leaf concentration of others. For example, Hewitt (1955) found that the

contents of N and K in Lacatan banana leaves were significantly lowered by excessive phosphate applications. A marked depression of leaf N by the application of high potash dressings was noted by Hewitt and Osborne (1962) and also by Ho (1969). Murray (1960) found that N and K deficiencies are associated with elevated leaf P, while P deficiency was associated with increased leaf K. With a small induced P deficiency a slight increase in foliar N was reported by Lacoenilhe and Martin-Prevel (1971b).

Concentrations of leaf nutrients depend upon the stage of development of the plant. In an attempt to determine the best growth stage to sample, Hewitt (1955) determined leaf concentrations both at the time of shooting and at the time of maturity of the fruit. Since the nutrient concentrations at shooting were generally higher, this stage was chosen for the time of sampling in subsequent work (Hewitt and Osborne, 1962). This sampling had previously been used by Bidner-Barhava and Ravikovitch (1958) and Murray (1959). For plants younger than the shooting stage, the stage of development greatly effects the nutrient contents of fully expanded leaves (Boland, 1960). Boland suggested sampling at age 6 to 8 months. In Taiwan, correlations between leaf K and banana yield were best about 6 months after planting (Ho, 1969). Leaf nutrient contents were greatest at this stage. The influence of plant development on leaf nutrient levels was studied by Twyford and Coulter (1964). Leaves of young Robusta plants 3 to 4 feet high contained more N, P, and K than older plants which had not shot flowers. Nutrients were usually less concentrated in plants after shooting than before. They suggest that sampling be done sometime before shooting. Dumas (1958, 1960)

obtained best results in West African field experiments with Gros Michel, Dwarf Cavendish, and Poyo bananas when samples were taken at harvest. Third leaf N, K and P of Gros Michel bananas in Hawaii declined with increasing plant age from 6 to 10 months (Gabuin, 1969). However, these plants were receiving N and K fertilizers at a constant rate (3 month interval) as the plants increased in size. A decrease in composition would be expected under these conditions.

Seasonal changes influence leaf nutrient composition of bananas. On the eastern slopes of the Cameroon Mountains rainfall is rather abundant during July-October, but November to March is dry. In this region N, P, and K in leaf No. 1 of Lacatans were significantly lower during the dry season (Brzesowsky and Van Biesen, 1962). In New South Wales, Australia, nutrient concentrations in the third leaf of Giant Cavendish were considerably lower in mid-winter than in summer (Turner and Barkus, 1970). Factors which vary seasonally there are temperature and day length.

Nutrient concentrations may vary within a given banana leaf. In studying this problem Twyford and Coulter (1964) used a large number of leaves from banana plants of different sizes. The leaves were divided into base, middle, and apex portions and analyses of N and K concentrations were made on these separate portions. A statistical examination of the results showed the base of the leaf had significantly more K than the middle which in turn contained more than the apex. In all cases the apex of the leaf contained significantly more N than the middle or base. Twyford and Coulter (1964) also studied the fourth leaf from three vigorously growing 6-month old plants. These leaves

cut into tenths which were analyzed separately. For comparison, samples were also analyzed from each side of the lamina. Although there were considerable differences between the two lamina halves taken section by section, when averaged over the whole length they were not significantly different for any nutrients considered. Unlike N and K, P content varied little from one leaf portion to another.

Recently, Lahav (1972) has reported variation of K content along the length of a banana leaf (from 4.74% near the base to 2.57% near the apex). In this work leaf No. 3 was divided into 10 sections and samples were analyzed separately from the two lamina halves of each section. In 7 of the 10 sections the K content of the leaf on the left side of the mid-rib (looking towards the apex) was greater than on the right side. However, these differences were not statistically significant. It was noted that significant differences of this type may be attained when one side of the leaf receives more direct sunlight than the other. In this regard entire leaves which were in direct sunlight most of the day had an average K content of 2.78% while those that were shaded most of the day had an average of 3.63% K. This is in agreement with Murray (1961) who noted that shading caused a marked accumulation of P and K in the leaf but had no effect on N.

III. MATERIALS AND EXPERIMENTAL METHODS

The field portion of this study was located in field Z-3, Waimanalo Experiment Farm, University of Hawaii. The site is about 2 acres of gently sloping Kawaihapai clay loam. Some aspects of weather conditions during 1971-1972 are given in Table 6. Mean monthly maximum temperature ranged from 76.5 to 85.8°F, and minimum temperature ranged from 62.9 to 73.5°F. Monthly rainfall ranged from 0.5 to 12.3 inches and totaled 38.9 inches in 1971 and 36.8 inches in 1972 with most of it falling during the period December to April. Rainfall was supplemented by sprinkler irrigation at the rate of about 2 inches every 4 to 5 days when needed.

Experimental Design

The experimental field was fallowed for one year. Magnesium sulfate was applied to the total area at 100 lbs. Mg/acre. One half of the field was given 200 lbs. P/acre in the form of treble superphosphate, and Eptam was applied for the control of nutsedge over the whole area. All of these materials were broadcast and disked into the soil. Planting material was obtained from a banana nursery which had been established during July 1970 using cleaned, heat-treated Giant Cavendish corms supplied by the Oahu Banana Growers Association.

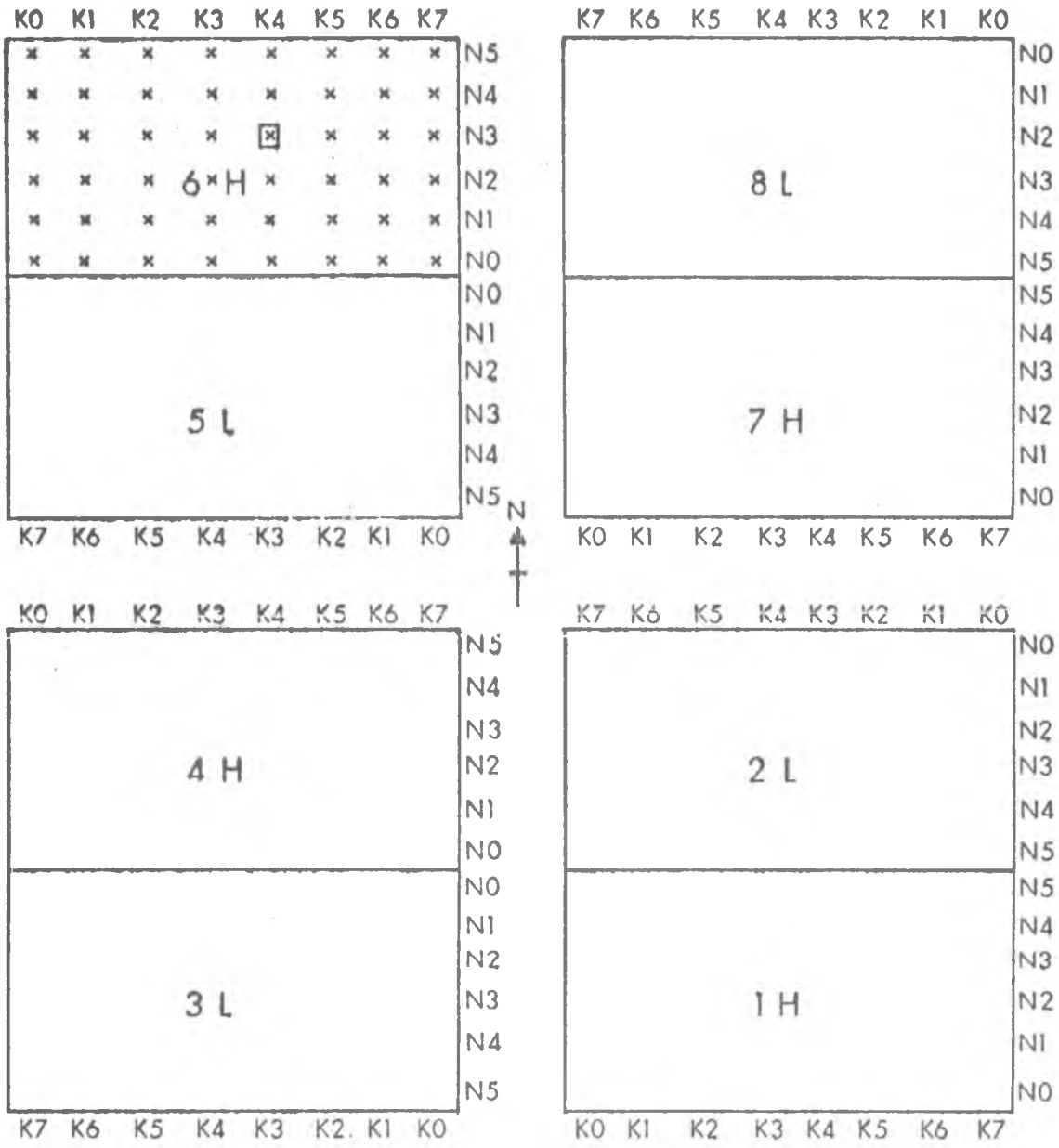
The experimental area was planted during the week of July 12, 1971. In order to control grasses and weeds other than nutsedge a preemergence herbicide, EVIC (Ametryne), was applied over the field at the rate of 6.4 lbs. of active ingredient per acre and sprinkler irrigated immediately.

Eight blocks of 48 corms each were planted as shown in Figure 1. Blocks 1 to 4 received the pre-plant phosphate treatment described

Table 6. Mean monthly maximum and minimum temperatures and monthly rainfall for 1971-1972 at Waimanalo Experimental Station.

Month	Year 1971			Year 1972		
	Maximum temperature (°F)	Minimum temperature (°F)	Rainfall (inches)	Maximum temperature (°F)	Minimum temperature (°F)	Rainfall (inches)
January	76.5	62.9	12.26	77.3	63.6	11.09
February	80.0	65.1	2.54	76.5	64.6	5.22
March	78.8	67.6	2.65	78.8	64.6	3.08
April	79.5	68.9	3.17	78.1	67.8	5.28
May	81.5	70.7	0.98	81.3	69.9	0.55
June	82.0	70.2	4.19	82.7	70.4	1.05
July	83.3	71.7	0.46	84.1	72.7	0.58
August	84.6	71.8	1.91	85.6	73.5	1.29
September	84.9	72.1	2.30	85.8	72.1	0.46
October	83.3	71.4	2.53	85.0	71.9	2.96
November	80.5	70.8	1.70	83.0	69.2	2.17
December	78.5	68.5	4.22	78.6	63.5	3.09
Total	-	-	38.91	-	-	36.82
Mean	81.1	69.3	-	81.4	68.6	-

Figure 1. Banana experiment block layout and plan for N and K fertilizer applications. Phosphate was applied to blocks 1, 2, 3 and 4. High (H) and low (L) plant densities are indicated. Individual plants are denoted by x. x denotes control plant.


K0 K1 K2 K3 K4 K5 K6 K7
N5
N4
N3
6 H
N2
N1
N0
5 L
K7 K6 K5 K4 K3 K2 K1 K0
K7 K6 K5 K4 K3 K2 K1 K0
8 L
7 H
K0 K1 K2 K3 K4 K5 K6 K7
N
4 H
3 L
2 L
1 H

above while blocks 5 to 8 did not. Blocks consisted of 6 rows of 8 plants. To accommodate the sprinkler irrigation system, plants were spaced 10 feet in rows 15 feet apart. The plan for nitrogen and potassium applications is indicated in Figure 1. This arrangement has been referred to as a "continuous function experimental design" (Fox, 1973a). Six levels of N and 8 levels of K fertilizer were used in such a way that each plant in a block received an N-K combination different from every other plant in that block. Along each row potassium treatments were increased progressively from none applied (K-0) to an amount considered excessive (K-7). Nitrogen levels were increased from row to row across the K treatments, with the first row receiving none (N-0) and the sixth row receiving an excessive amount (N-5). This design is particularly useful for experiments with crops having a wide spreading root system, such as bananas, where border effects may become significant. The continuous function design minimizes such effects provided that the increments of applied nutrients are small. Furthermore, border effects tend to cancel out, being positive in one direction and negative in the other (Fox, 1973a).

The plant receiving intermediate N and K applications (N-3, K-4) was used as a control plant in each block. Periodically, a section of the third fully unfurled leaf from the dominant pseudostem was sampled and analyzed. Hewitt (1955) and others consider this leaf to be the best indicator of plant nutrition. The sample was obtained from both sides of the midrib halfway between the tip and base of the leaf since nutrients are not uniformly distributed in the leaf (Twyford and Coulter, 1964; Lahav, 1972). These "control samples" were taken from

plants which had not yet flowered but were approaching full stature. Frequency and rate of fertilization were adjusted in an attempt to maintain control leaves at 2.6% N, 3.3% K and 0.18% P. These are the critical levels for the third leaf at the time of shooting as determined by Hewitt and Osborne (1962) for Lacatan bananas in Jamaica. As a first approximation it was assumed that these concentrations were adequate for Giant Cavendish in Hawaii. When percentage N or K in the control plant of a given block fell below these values, N or K fertilizer was applied to that block. Amounts applied for the various treatments were in a fixed ratio. Thus nitrogen in treatments N-0 through N-5 was always applied in the ratio of 0 : 1 : 3 : 5 : 7 : 9. Similarly, potassium treatments K-0 through K-7 were always in the ratio of 0 : 1 : 3 : 5 : 7 : 9 : 11 : 13. Details of N and K treatments are discussed in a later section. There was never reason to apply phosphate fertilizer. As later data will demonstrate, bananas from the minus P blocks were above the critical P concentration.

Plant density was maintained at two levels as indicated in Figure 1. In the low density (L) blocks the original plant and two suckers were allowed to develop. In the high density (H) blocks four suckers were allowed to develop along with the original plant. All other suckers were cut off at ground level periodically.

Plants were inspected for flowering (shooting) each week. At the onset of flowering leaf samples were taken from the third youngest leaf lamina as described for control plants. Hewitt (1955) and others found that leaf nutrient concentrations were greatest at the shooting stage and suggested that it be used in studies relating leaf nutrient

concentrations and yield. Bunch weight (yield) was determined for each plant at the commercial harvest stage.

Preliminary Study of N and K Distribution in Plants

The investigation to determine leaf to leaf variation of nutrient concentrations involved selected plants from blocks 3 and 4. To study the N distribution, all leaves on plants in the rows receiving the intermediate K fertilizer treatment, K-4, were sampled at the shooting stage and analyzed. Each plant in such a row receives a different level of N fertilizer (see Figure 1). Similarly, to study the distribution of K all leaves from plants receiving the intermediate nitrogen treatment, N-3, were sampled at the shooting stage and analyzed. Samples were taken from both sides of the midrib, halfway between the tip and base of the leaf.

A study of the distribution of N and K along the leaf axis was made using those plants in blocks 1, 2, 3 and 4 receiving the K-3 potassium treatment. Separate samples were obtained from the base, mid-section and top of the third leaf of these plants sometime before the shooting stage. All samples consisted of material from both sides of the leaf midrib. Before chemical analysis, composites were made of samples from blocks 1, 2, 3 and 4 receiving the same nitrogen treatment.

In order to determine whether significant differences occurred in the N content halves of the leaf lamina separated by the midrib, a study involving those plants in blocks 1, 2, 3 and 4 which received no potassium, K-0, and nitrogen treatments N-0, N-3 and N-5 was carried out. Separate samples were obtained from each side of the midrib (midway between the leaf tip and the leaf base) of the third youngest and

oldest (bottom) leaves on the plant sometime before the shooting stage.

Problems Encountered in Control Plant Sampling

As discussed already, plants receiving treatments (N-3, K-4) were used as control plants. It is known that the leaf concentrations of N and K decrease considerably after shooting (Twyford and Coulter, 1964). After the control plant flowers it is no longer suitable as a control. Sampling was then shifted to the next largest plant in the mat if a suitable pseudostem was available. However, when plants are young (less than 5 to 6 months old) leaf N and K are quite high (Twyford and Coulter, 1964). Composition of young plants cannot be directly compared with older plants.

One approach is to use plants surrounding the original plant; in other words, composite leaf tissue from plants receiving treatments (N-2, K-4), (N-4, K-4), (N-3, K-3) and (N-3, K-5) (see Figure 1). Third leaves of control plants (approaching full stature but before shooting) and of four surrounding plants (also before shooting) in blocks 1, 3, 4 and 8 were sampled and analyzed for N and K. Results of these analyses are presented in Tables 7 and 8. Differences between N and K concentrations of the control plant and the average N and K concentrations of surrounding plants were not statistically significant. Although mean N percentage of the N-4 treatment was greater than N-2, overall mean of the N-2 and N-4 treatments was little different from the (N-3, K-4) control. Thus, surrounding plants may be used as a composite source of control leaf tissue. In practice composite samples of three or four plants were used if the regular control plant was unsuitable.

Table 7. Percent N in control plant and surrounding plants.

Block	% N in control plants x-3-4	constant N plants		constant K plants		Total
		% N x-3-3	% N x-3-5	% N x-2-4	% N x-4-4	
1	2.43	2.21	2.44	2.16	2.48	11.72
3	2.43	2.97	2.59	2.65	3.05	13.69
4	2.54	2.53	2.60	2.67	2.62	12.96
8	3.03	2.42	2.70	2.60	2.87	13.62
Total	10.43	10.13	10.33	10.08	11.02	51.99
$\bar{X}$	2.61	2.53	2.58	2.52	2.75	2.60

Table 8. Percent K in control plant and surrounding plants.

Block	% N in control plants x-3-4	constant N plants		constant K plants		Total
		% K x-3-3	% K x-3-5	% K x-2-4	% K x-4-4	
1	2.70	2.80	2.75	3.18	2.65	14.08
3	2.70	2.70	2.78	3.20	2.17	13.55
4	3.25	2.70	3.20	3.10	2.85	14.90
8	2.50	2.84	2.88	2.85	2.73	13.80
Total	11.15	10.84	11.61	12.33	10.40	56.33
$\bar{X}$	2.79	2.71	2.90	3.08	2.60	2.82

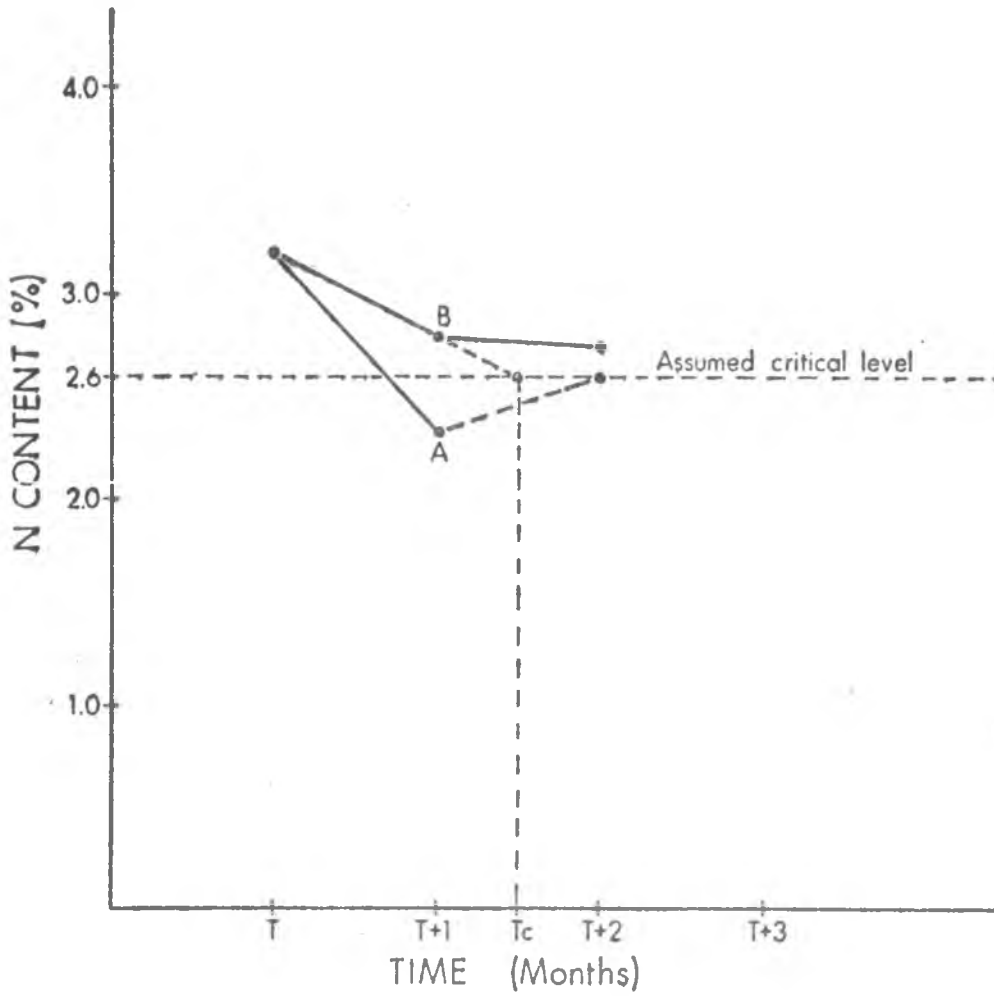
N and K Applications

Amounts and frequency of application of N and K fertilizers for banana depend upon many factors, including soil, climate, water supply and variety. In general, 100-200 g N per mat per year split into 3 or 4 equal applications is adequate (Butler, 1960; Brzesowsky and Biesen, 1962; Hewitt and Osborne, 1963; Jordine, 1963; Hagin et al., 1964; Valmayor et al., 1965). These same reports indicate that 150-550 g K per mat per year is required. The number of K applications per year is not important (Hewitt and Osborne, 1963).

In this experiment control plants received 47 g N (100 g urea) per application. Nitrogen was applied when third leaf N of control plants fell below 2.6%. At the same time N was applied to all plants in the block in amounts determined by the prescribed ratio given earlier.

Consider the example presented in Figure 2. At time T a control leaf contained significantly more N than the assumed critical level. Therefore no N fertilizer treatment was applied. One month later, the control plant was analyzed again. Two possible results are indicated in Figure 2 as points A and B. In case A, the N level had fallen below 2.6% and 47 g N was applied to the control plant. By T + 2, the plant had responded as shown in Figure 2. On the other hand, in case B the N level at T + 1 month was still above the assumed critical level. An estimate of the time Tc at which the N content will fall to 2.6% and N applications will be required may be made by extrapolating the plot to the assumed critical level as shown in Figure 2. If fertilization is delayed until Tc, the full amount of 47 g N will be applied at that time. In a situation where more than 4 months has

Figure 2. Possible actions the experimenter may take in response to two hypothetical courses the N content of a control plant may follow. At time T + 1 month control plant A falls below the assumed critical level while B is still above that level. In case A the full amount of fertilizer (47 g N) is applied. In case B either half the full amount is applied at T + 1 or the full amount is applied at Tc, the calculated time at which the critical level is reached.


4.0
3.0
2.6
2.0
1.0
N CONTENT (%)
B
A
Assumed critical level
T
T+1
Tc
T+2
T+3
TIME (Months)

passed since N was last applied, fertilizer would be used at T + 1, but in the reduced amount of 23 g N.

The amount of potassium fertilizer used was 150 g K (303 g KCl) per treatment to the control plant. Such an application was made whenever the K concentration in the control leaf fell below the assumed critical level of 3.3% K.

Results of leaf analyses and amounts of fertilizer applied to control plants during the first year are presented in Tables 9 and 10. Nitrogen was added as urea; potassium as KCl except that for the first application K_2SO_4 was used. Fertilizer was broadcast in bands with outside radii of 2 to 3 feet around the plant.

Foliar analyses of control plants were begun after the plants were 5 months old. Note from Tables 9 and 10 that about 3 weeks and 5 months after planting large applications were made of both N and K. It was not surprising that first leaf analyses (December 20, 1971) detected more N and K than the assumed critical levels. No further fertilizer applications were made for a time which allowed concentrations to decrease. Analyses of leaves sampled on April 26 showed that N contents of control leaves in blocks 1 to 4 were below 2.6% and those in blocks 5 to 8 were still above this level. Nitrogen was applied to control plants in blocks 1 to 4 on May 17. Since the magnitude and duration of response to treatment were unknown, 23 g N was used instead of the full 47 g N for this application. Partial recovery was apparent 20 days after the treatment and after 30 days control leaves in all 4 blocks contained more than the assumed critical level. In order to keep control plant N levels near 2.6%, 47 g of nitrogen (100 g urea)

Table 9. Percent N in control leaves and N applications made to control plants during the first year.

	Year 1971					Year 1972						
Block	8/4	12/8	12/20	3/8	4/26	5/17	6/7	6/20	6/23	7/5	7/21	8/23
1	495 g urea added	495 g urea added	3.14	3.00	2.46	50 g urea added	2.40	2.67	100 g urea added	2.64	100 g urea added	2.30
2			3.38	2.48	2.54		2.98	2.95		2.52		2.39
3			2.98	2.91	2.64		2.73	2.61		2.34		1.88
4			3.03	3.14	2.48		2.52	2.66		2.49		2.27
5			3.72	2.76	3.83	-	3.76	-	-	3.45	-	2.73
6			3.36	3.00	2.98	-	3.24	-	-	3.12	-	2.60
7			3.44	3.57	3.36	-	3.50	-	-	3.21	-	2.49
8			3.20	3.54	3.55	-	3.50	-	-	2.97	-	2.64

Table 10. Percent K in control leaves and K applications made to control plants during the first year.

	Year 1971					Year 1972			
Block	8/7	12/7	12/20	3/8	4/26	5/10	6/7	7/21	8/23
1			4.01	3.96	3.41	-	3.87	-	2.95
2			3.80	4.97	3.66	-	3.38	-	2.65
3	722 g K_2SO_4 added	605 g KCl added	3.59	3.71	3.26	-	4.29	-	3.25
4			4.01	4.03	3.41	-	4.64	-	3.15
5			4.01	3.86	2.69	303 g KCl added	2.86	303 g KCl added	2.48
6			3.48	3.47	2.76		3.45		3.35
7			4.05	3.59	2.99		3.26		2.70
8			3.48	3.41	2.65		3.06		2.95

was applied on June 23 and again on July 21. These applications were necessary only for control plants in blocks 1 to 4.

Potassium contents of control leaves for blocks 5 to 8 were lower than the assumed critical level of 3.3% on April 26 (see Table 10). Fertilizer was applied on May 10 at the rate of 158 g K per control plant. Partial recovery occurred after about 30 days.

Leaf Analysis

Samples were oven-dried at 65°C for 24 hours and ground in a laboratory Wiley mill through a 20-mesh screen. Analyses were made for total nitrogen, potassium, phosphorus, and in some cases, certain other elements.

Total nitrogen was determined by the Kjeldahl method (Jackson, 1958). Dry leaf tissue (1 g) was digested with concentrated sulfuric acid (30 ml) in the presence of selenium (1 ml 20% $Na_2SeO_4 \cdot 10H_2O$), sodium sulphate (7.5 g Na_2SO_4), and cupric sulphate (0.5 g $CuSO_4 \cdot 5H_2O$). During the digestion, organic nitrogen was converted to ammonia and all organic matter was oxidized. The ammonia formed was distilled into boric acid and titrated with standard acid. Preliminary analyses had indicated the nitrate content of banana leaves was negligible. Therefore the modified procedure to include nitrate in the total N analyses was not used.

For potassium, phosphorus, and sulfur measurements a solution was prepared by digesting 0.5 g dry leaf tissue with 15 ml of an acid oxidizing solution which was a 1 : 2 mixture of 70% $HClO_4$ and concentrated HNO_3 (Jackson, 1958). The leaf tissue was digested in the cold acid overnight in a microkjeldahl flask and then heated 10 to 15

minutes into the white fuming stage to complete digestion. The acid digest was transferred to a 50 ml volumetric flask and diluted to volume.

Potassium was determined using a Coleman flame spectrophotometer. A small amount of the digest solution prepared as discussed above was flamed and the emission at 767 mμ measured. An estimate of the potassium content was then obtained from a curve made from measured emissions of standard potassium solutions.

The phosphorus content was determined as phosphomolybdenum blue colorimetrically with a Technicon Auto Analyzer (Dickman and Bray, 1940). Light transmission of the solution at 660 mμ was measured. An estimate of the phosphorus concentration was then obtained by comparing this result with the transmissivities of standard solutions.

Sulfur in the extract was determined by turbidimetric measurement (Beaton et al., 1968). When 5 ml of extract was mixed with 1 ml 0.5% gum acacia, 3 ml water and 1 ml 50% $MgCl_2$, all sulfur compounds were converted to sulfate. $BaCl_2$ (0.5 g) was dissolved in the solution and it was allowed to stand for exactly 5 minutes. The absorbance of the suspended $BaSO_4$ precipitate was measured at 430 mμ with a spectrophotometer. Sulfur was estimated by comparing this result with a standard curve.

During the first year after planting a number of leaf samples were analyzed by the Soil Testing and Plant Analysis Laboratory of the University of Georgia, In these analyses total nitrogen was determined by the AOAC method, while potassium, phosphorus, and other elements were measured spectrographically.

Soil Sampling and Analysis

Soil samples were collected from the experimental area about 6 and 22 months after planting. At 6 months, a composite was made for each block using 10 sub-samples taken at 0-6 inches. These sub-samples were taken from unfertilized areas (N and K) between mats from all parts of the block. At 22 months composite samples were made for blocks 1 to 4 and 5 to 8 for each K treatment level. Twelve sub-samples were used for each composite, three from each K treatment row. They were taken randomly along the row at 0-6 inches. All composite samples were air dried and then seived through a 20-mesh screen.

Soil moisture was determined as the weight loss of 10 g samples when oven-dried overnight at 105°C. The pH was measured with a Beckman glass-electrode pH meter using a mixture of 10 g of soil (oven dried basis) and 10 ml of distilled water.

Total nitrogen was determined by the Kjeldahl method (Jackson, 1958) using 5 g (oven dried basis) samples. The procedure was the same as that described earlier for leaf tissue.

Nitrate-nitrogen released by the soil during incubation was found using the method of Stanford and Hanway (1955). A 20 g (oven dried basis) soil sample was mixed with vermiculite, placed in a filter tube and leached free of nitrate with distilled water. After incubation for 10 days in a humid chamber at 30°C, the sample was extracted. The nitrate produced during the incubation period was then determined using the phenoldisulphonic acid method (Horwitz, 1960). A 5 ml aliquot of the leachate combined with 1 ml of saturated $Ca(OH)_2$ was evaporated to dryness and 1 ml of phenoldisulphonic acid was added to the residue.

After 10 to 15 minutes, 15 ml of water was added and then 5N NaOH was slowly added in excess of that needed to fully develop a yellow color. The nitrate release during incubation was then estimated by measuring the optical density of the solution at 430 mμ with a spectrophotometer and comparing the result with a standard curve.

A modified Truog method was used to determine available phosphorus in the soil (Ayres and Hagihara, 1952). A 3 g soil sample (oven dried basis) was extracted for 20 minutes with 300 ml of 0.02N sulfuric acid containing 3 g of ammonium sulfate per liter and then filtered. Phosphate in the extract was determined colorimetrically using phosphomolybdenum blue as described for leaf tissue. After the blue color was developed the optical density of the solution was measured at 660 mμ with a spectrophotometer. The phosphate estimate was made by comparing this measurement with a standard curve.

The phosphate sorption capabilities of the soil were investigated using the procedure described by Fox and Kamprath (1970). Three gram soil samples (oven dried basis) were equilibrated for 6 days at 20°C in 30 ml of 0.01 M $CaCl_2$ containing various amounts of $Ca(H_2PO_4)_2$. Equilibration was carried out in 50 ml plastic centrifuge tubes. These were shaken longitudinally for a 30 minute period twice daily. After centrifugation phosphorus in the supernatant was determined colorimetrically as described in the preceding paragraph. The phosphorus which disappeared from solution was considered to have been sorbed.

In order to determine exchangeable potassium in the soil, a 3 g sample (oven dried basis) was extracted 3 times for 30 minutes with 30 ml portions of 1 N NH_4OAc adjusted to pH 7 and then filtered

(Jackson, 1958). Potassium in the filtrate was measured with a Coleman flame spectrophotometer as described for leaf tissue.

The potassium-calcium exchange equilibria of the soil was also studied. Five 3 g soil samples (oven dried basis) were put into 50 ml centrifuge tubes. These samples were equilibrated for 6 days at $20^{o}C$ in 30 ml of solution made by combining various proportions of 0.01 M KCl and 0.005 M $CaCl_2$. Tubes were shaken twice daily for 30 minutes over the 6 days period. After centrifugation, the potassium content of the supernatant was determined with a Coleman flame spectrophotometer as discussed for leaf tissue. A Perkin-Elmer model 303 atomic absorption spectrophotometer was used for calcium and magnesium determinations. The potassium and calcium which disappeared from solution were considered to have been sorbed, while the magnesium in solution was considered to be the result of desorption.

IV. RESULTS AND DISCUSSION

Nutrient Status of Soils

Analytical results of soil samples collected at 6 months are given in Tables 11-12 and Figures 3-4. Mean pH was 6.8 for blocks 1 to 4 and 7.0 for blocks 5 to 8. These values are considered favorable since bananas grow successfully in soils ranging from pH 4.5 to 8.0. However, highest yields are obtained in soils with pH 6 to 6.7 (Champion et al., 1958).

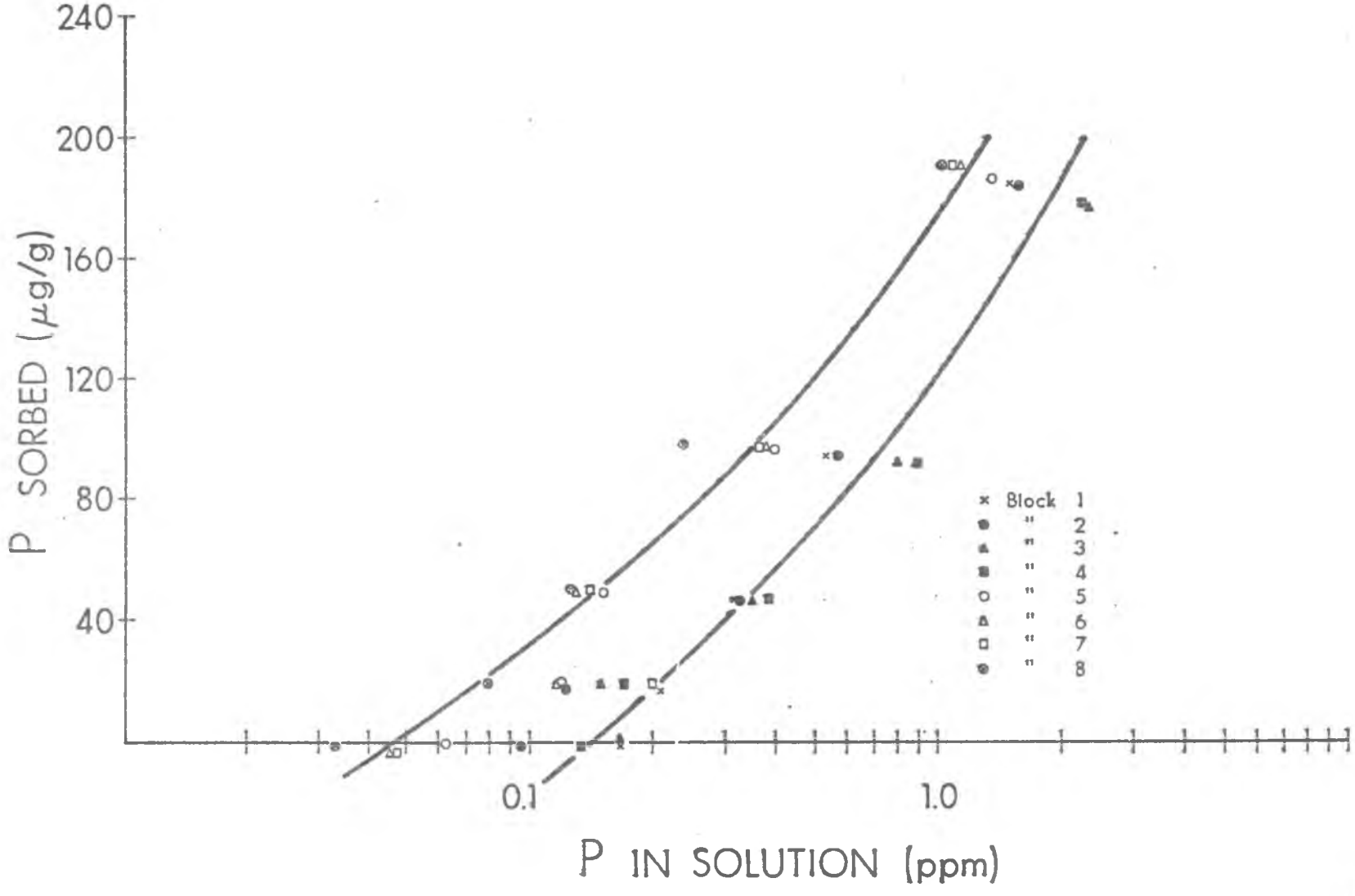
Mean total nitrogen was 0.109% for blocks 1 to 4 and 0.096% for blocks 5 to 8 (Table 11). Although total N was highest in blocks 1 to 4 symptoms of N deficiency were most severe in these blocks. Furthermore, more N fertilizer was required for blocks 1 to 4 than 5 to 8 (Table 9). Nitrification was slightly lower in blocks 1 to 4 (mean 17.27 ppm) than in blocks 5 to 8 (mean 20.85 ppm).

Extractable P from P fertilized blocks averaged 477 ppm, while blocks which were not P fertilized averaged 375 ppm. The phosphate sorption curve in Figure 3 indicates that P in solution was about 0.18 ppm for P fertilized blocks and 0.05 ppm for blocks which were unfertilized with P. These values are comparable with P concentrations in soil solutions at which most plants attain near maximum growth (Fox and Kamprath, 1970). No P deficiency symptoms were recognized in the banana and, as will be discussed in the next section, P content of leaf tissue was generally adequate even in blocks which were not P fertilized. The phosphate requirement of Cavendish bananas is reputed to be low (Pelegrin, 1953). The truth of this observation cannot be tested here because the soil was well supplied with extractable P and the intensity of P nutrition was adequate for many crops (Fox et al.,

Table 11. Some pertinent analyses of soil samples taken 6 months after planting from blocks 1 to 8, Banana Studies, Waimanalo Experimental Farm.

Block	pH	Total N (%)	Nitrification rate (10 days) (ppm)	Extractable P (ppm)	Exchangeable K (meq/100 g)
1	6.84	.115	16.4	460	1.45
2	6.74	.106	14.7	460	1.20
3	6.83	.106	20.0	490	1.22
4	6.88	.109	18.0	500	1.45
5	7.05	.095	19.1	380	1.00
6	6.97	.109	20.9	350	0.91
7	7.08	.084	22.4	390	1.07
8	7.10	.095	21.0	380	0.94

Figure 3. Mean phosphate sorption by soil in phosphate fertilized blocks (1 to 4) and blocks which had not been phosphate fertilized (5 to 8). Data points for individual blocks are also indicated. Samples were taken 6 months after planting.


240
200
160
120
80
40
P SORBED (µg/g)
0.1
1.0
P IN SOLUTION (ppm)
Block 1
" 2
" 3
" 4
" 5
" 6
" 7
" 8

1974).

Mean exchangeable K was 1.33 meq/100 g for blocks 1 to 4 and 0.98 meq/100 g for blocks 5 to 8 (Table 11). Table 12 shows the cations in equilibrated solutions (0.01 M Cl) when various concentrations of K and Ca are added. Potassium withdrawn from the soil (K in solution when no K was added) was generally higher in blocks 1 to 4 than in blocks 5 to 8. Potassium in solution was plotted against K sorbed by the soil in Figure 4. Potassium in the soil solution at zero K added or withdrawn was 0.30 meq/l for blocks 1 to 4 and 0.16 meq/l in blocks 5 to 8. These levels are considered low for good K nutrition of some crops grown in pots. Grimme et al. (1971) found that optimum yields of grain were obtained with 0.6 to 0.8 meq/l. However, in Hawaii there is evidence that borderline K deficiency for banana is associated with an equilibrium concentration of about 0.2 meq/l K in 0.01 M chloride (Fox, 1973b). In agreement with these data, more K fertilizer was required for blocks 5 to 8 than 1 to 4 (Table 10). Calcium and Mg in equilibrated 0.01 M Cl was approximately equal in blocks 1 to 4 and blocks 5 to 8 (Table 12).

Soil samples taken at 6 months were equilibrated in 0.0025 N K and/or Ca chloride solution. Potassium in solution was plotted against K sorbed by the soil (Figure 5). Potassium in equilibrated solution corrected to zero K desorbed was .095 meq/l for blocks 1 to 4 and .030 meq/l for blocks 5 to 8. After 22 months soil samples for the various K treatments were equilibrated with 0.0025N $CaCl_2$. K in solution corrected to zero K desorbed, ranged from .042 meq/l (K-0) to .470 meq/l (K-7) in blocks 1 to 4 and .030 meq/l (K-0) to .465 meq/l

Table 12. Cations in equilibrium soil solutions when various concentrations of K and Ca are added. Values are averages from blocks 1 to 4 and 5 to 8. Samples were taken 6 months after planting.

Cation added (meq/1)		Cation in solution (meq/1)					
		Blocks 1 to 4			Blocks 5 to 8		
K	Ca	K	Ca	Mg	K	Ca	Mg
0.0	20.0	.23	4.32	4.72	.13	4.14	4.81
0.1	19.9	.24	4.18	4.65	.13	4.19	4.85
0.4	19.6	.25	4.23	4.76	.16	4.04	4.94
1.6	18.4	.44	4.58	4.63	.32	3.94	4.86
6.4	13.6	1.13	3.80	4.57	.93	3.54	4.78

Figure 4. Mean potassium sorption by soil in blocks 1 to 4 and 5 to 8 equilibrated in 0.01M chloride solution. Data points for individual blocks are also indicated. Samples were taken 6 months after planting.

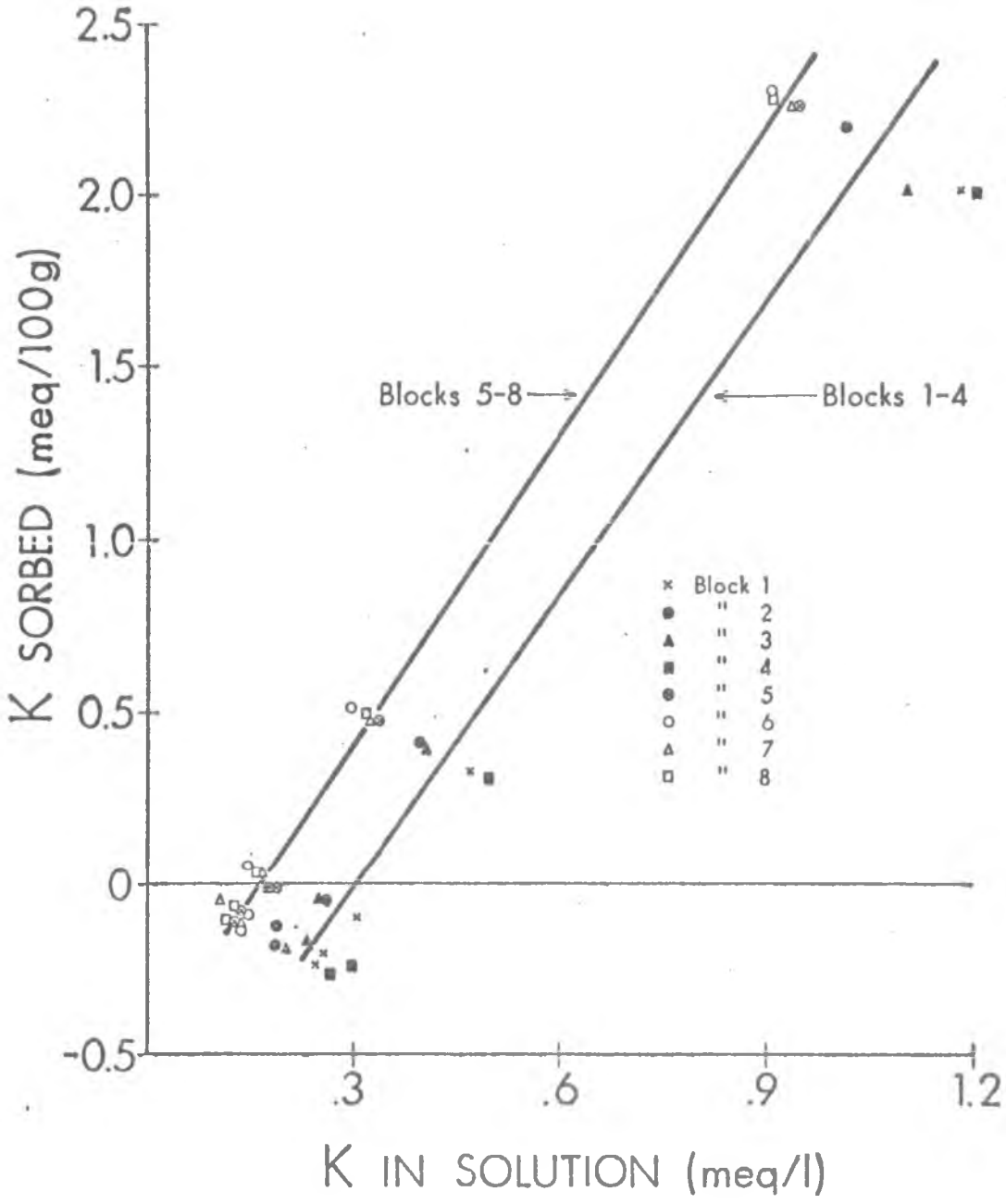
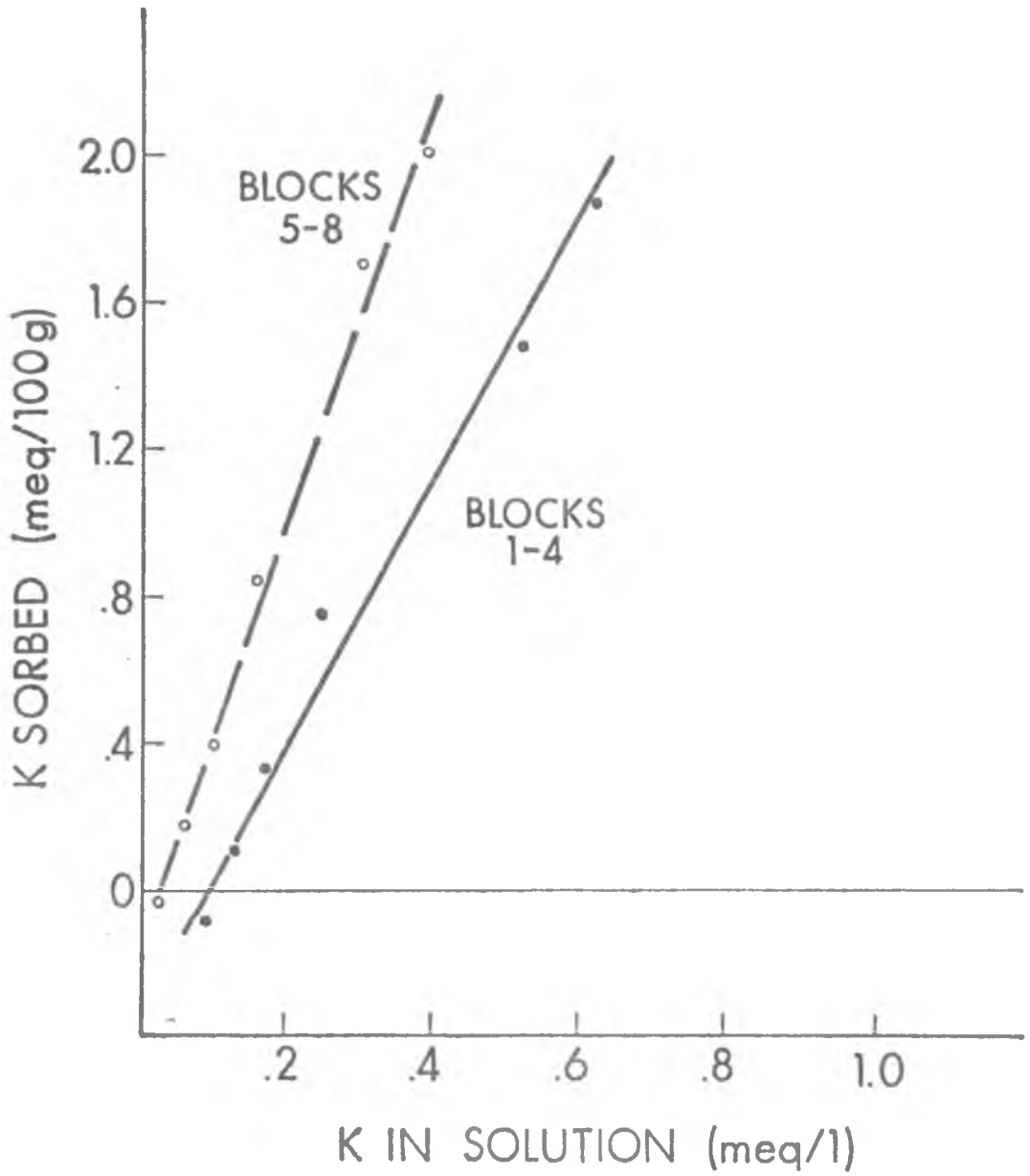

2.5
2.0
1.5
1.0
0.5
0
-0.5
.3
.6
.9
1.2
K SORBED (meq/100g)
K IN SOLUTION (meq/l)
Blocks 5-8
Blocks 1-4
× Block 1
● " 2
▲ " 3
■ " 4
● " 5
○ " 6
△ " 7
□ " 8

Figure 5. Mean potassium sorption by soil in blocks 1 to 4 and blocks 5 to 8 equilibrated in 0.0025N Ca and/or K chloride solution. Samples were taken 6 months after planting.


2.0
1.6
1.2
.8
.4
0
K SORBED (meq/100g)
BLOCKS
5-8
BLOCKS
1-4
.2
.4
.6
.8
1.0
K IN SOLUTION (meq/l)

(K-7) in blocks 5 to 8 (Table 13). Exchangeable K for each K treatment was also determined (Table 13).

The data show that K in equilibrated solutions increased slowly with increasing K fertilization up to treatment K-4. The increase with treatment was much greater beginning with treatment K-5. The soil apparently became saturated with adsorbed K at treatment K-5 (Nemeth et al., 1970). Another reason is that K treatments were in the form of KCl. No doubt some Cl was carried over into the soils being equilibrated, thus increasing the Cl concentration in systems being equilibrated to some value greater than .0025N. At high treatments residual chloride ions were accompanied by K in the systems being equilibrated.

Leaf N and K Distribution in Banana Plants

Samples of each green leaf of plants with treatment K-4 in blocks 3 and 4 were analyzed for N at the time of flowering. In Figure 6 leaf N is plotted against leaf number, beginning with the most recently unfurled leaf as number 1. The results are shown for all N treatment levels.

For any given leaf number, N increased with treatment until level N-2 was reached. Higher levels of N fertilization brought about little additional change in leaf N. The low N content for the treatment N-0 apparently was the result of nutsedge competition. This will be discussed in detail later.

In the case of treatments N-0 and N-1, N was most concentrated in the youngest leaves and tended to decrease with age (increasing leaf number). For the N-0 treatment, leaf N was most concentrated in

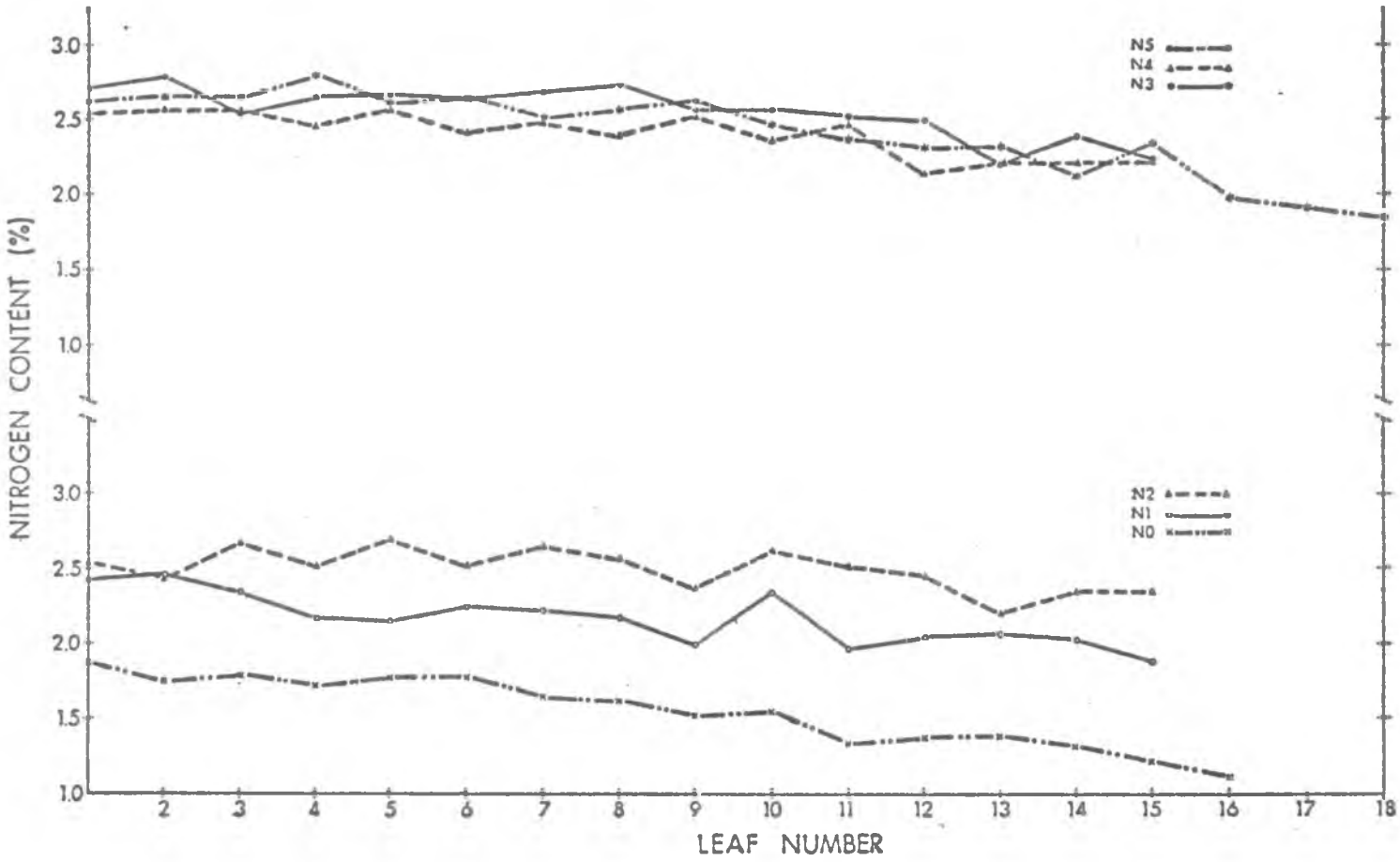
Table 13. Potassium in equilibrated chloride solution and exchangeable soil K for various K fertilizer treatments. Soil samples were taken at 22 months.

Treatment	Blocks 1 to 4			Blocks 5 to 8		
	K in equilibrated sol. (meq/l)[1]	K corrected to zero adsorbed (meq/l)[2]	Exchangeable K (meq/100g)	K in equilibrated sol. (meq/l)[1]	K corrected to zero adsorbed (meq/l)[2]	Exchangeable K (meq/100g)
K-0	.036	.042	0.64	.026	.030	0.54
K-1	.041	.051	0.51	.029	.035	0.43
K-2	.077	.095	0.83	.045	.053	0.64
K-3	.041	.051	0.60	.041	.050	0.62
K-4	.070	.090	1.11	.061	.070	0.81
K-5	.333	.420	2.71	.176	.200	1.62
K-6	.385	.486	2.52	.301	.355	2.39
K-7	.372	.470	2.69	.397	.465	3.19

[1] Equilibrating solutions were 0.0025 N with respect to Cl.

[2] Obtained by constructing lines through K in equilibrated solution parallel to lines on Figure 5 and determining the point of intersection at zero adsorption.

Figure 6. Leaf to leaf distribution of N at time of flowering in relation to N fertilization. Values are means from blocks 3 and 4. All plants were from the K-4 treatment.


N5
N4
N3
N2
N1
N0
NITROGEN CONTENT (%)
3.0
2.5
2.0
1.5
1.0
3.0
2.5
2.0
1.5
1.0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
LEAF NUMBER

leaf 1. Leaf 1 and leaf 2 of the N-1 plants had about the same N content. In the case of treatments N-2 to N-5, leaf N was high in the youngest leaf, but it then increased slightly to a maximum before decreasing with age. Maximum N was attained in the second to fifth leaf.

These results agree with a study by Murray (1960) who reported that in N deficient plants N was most concentrated in the No. 1 leaf. With plentiful N supply leaf N was maximum in leaf 4. Other studies also have shown that leaf N increases to a maximum and then falls off with age. In these studies maximum leaf N was reported in leaves ranging from No. 1 through No. 4 (Hewitt, 1955; Boland, 1959; Twyford and Coulter, 1962).

Leaves with maximum N when the N supply is adequate usually have been chosen for sampling in nutrition experiments. On this basis, leaves ranging from No. 2 to No. 4 have been selected by other investigators (Table 3). Figure 6 does not provide strong evidence for the choice of one leaf over another for sampling purposes. Considerable N variations occur from leaf to leaf and treatment to treatment. When results for all treatments with adequate N (N-2 to N-5) were averaged, maximum leaf N was in leaf 5. However, this maximum was only slightly greater than the concentrations for leaves 2 to 4. These results suggest that any leaf from the second to fifth may be chosen for sampling in future work with N and K.

Leaf-to-leaf K variation was studied using plants grown with a K fertilizer variable. All plants were from treatment N-3 in blocks 3 and 4. Leaf K at the time of flowering is plotted against leaf number

in Figure 7. There was little response of leaf K to K treatments. The probable reason is that K was reasonably well supplied by the soil. For every treatment, leaf K was higher in the youngest leaves than in the oldest. However, the rate of decline with age was not large, especially for the first 9 leaves. Other investigators also have reported highest leaf K in the youngest leaves and decreasing K with age (Hewitt, 1955; Boland, 1959; Twyford and Coulter, 1962; Turner and Barkus, 1970). Murray (1960) found that leaf K varied little with age when K was abundant but K was maximum in the first leaf and declined sharply in older leaves when the general level of K was deficient.

The results of N and K variations along the leaf axis are given in Table 14. For all N treatments, leaf N was most concentrated at the apex and least concentrated at the base of the leaf while leaf K was most concentrated at the base and decreased considerably towards the apex. Twyford and Coulter (1964) and Lahav (1972) have reported similar distributions. The middle leaf portion is probably best for sampling, since the concentrations of both N and K are approximately average.

In all three sections leaf N was least concentrated for intermediate N treatments (Table 14). The probable explanation for this is that the samples were taken on the same day which was before any of the plants flowered. Leaf nutrients tend to be greatest in very young plants and to decrease as the plant matures (Twyford and Coulter, 1964). Plants in blocks 1 to 4 with intermediate N treatment tended to flower earliest. When sampled, plants with intermediate N were closer to the shooting stage and thus lower leaf N should be expected since greater

Figure 7. Leaf to leaf distribution of K at time of flowering in relation to K fertilization. Values are means from blocks 3 and 4. All plants were from the N-3 treatment.

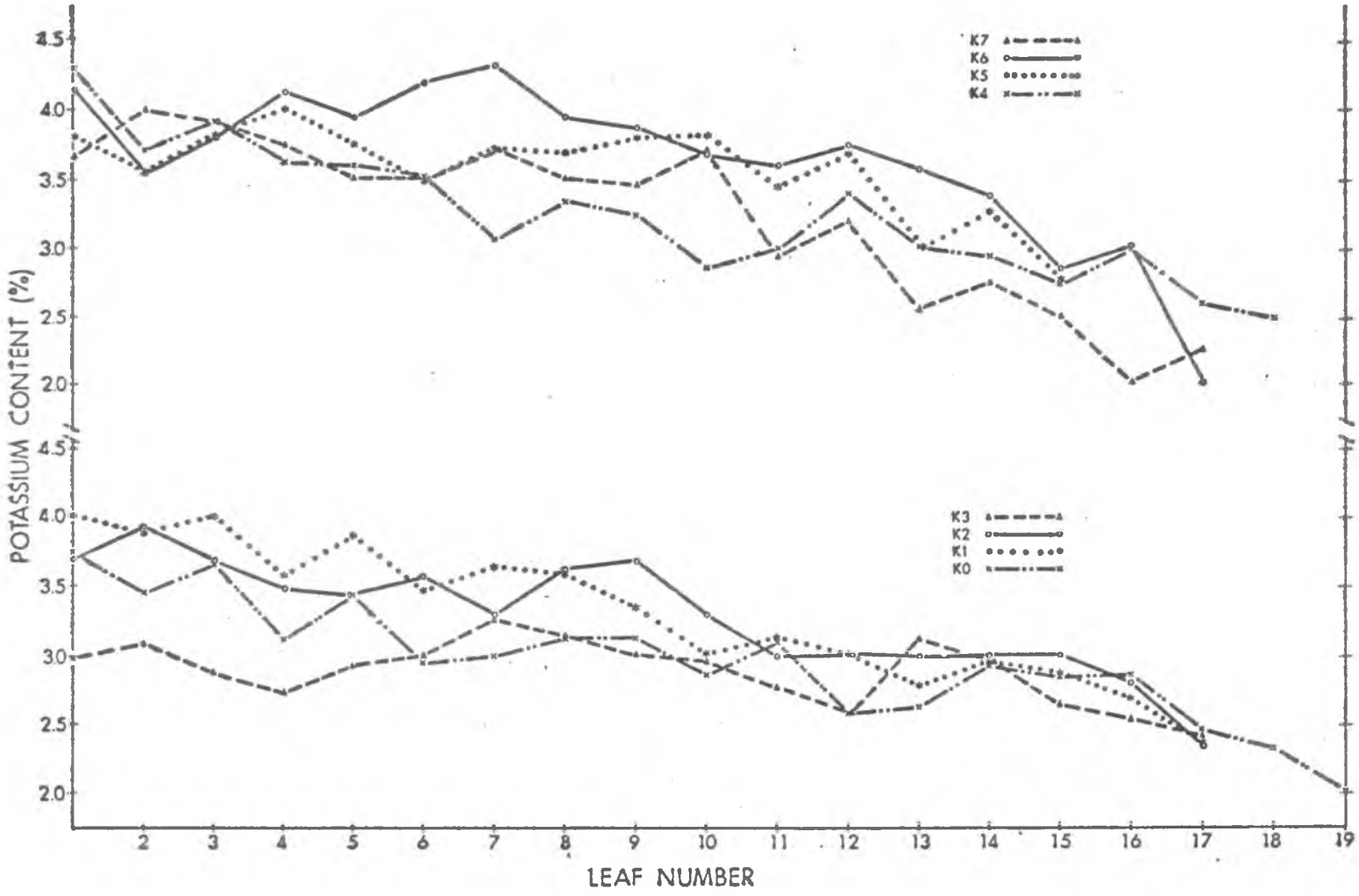

K7
K6
K5
K4
K3
K2
K1
K0
POTASSIUM CONTENT (%)
4.5
4.0
3.5
3.0
2.5
2.0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
LEAF NUMBER

Table 14. Percent leaf N and K in apex, middle and base portions of third leaf of banana for treatments N-0 through N-5 at K-3. Values are means of concentrations from blocks 1 to 4. Samples were taken from large plants which had not yet flowered.

Treatment	Nitrogen			Potassium		
	Apex	Middle	Base	Apex	Middle	Base
N-0 K-3	2.53	2.31	2.03	2.62	3.48	4.12
N-1 K-3	2.39	2.03	1.92	2.42	3.13	4.12
N-2 K-3	2.37	2.13	1.95	2.32	3.27	4.15
N-3 K-3	2.62	2.31	2.13	2.37	3.30	4.40
N-4 K-3	3.04	2.59	2.45	2.20	3.00	4.25
N-5 K-3	3.11	2.84	2.60	2.32	2.97	4.05
$\bar{X}$	2.68	2.37	2.18	2.37	3.19	4.18

maturity may have more than offset the effect of increased N supply. This is an important factor to consider in setting up sampling procedures for advisory work.

Leaf N did not vary significantly from one side of the leaf axis to the other (Table 15). Twyford and Coulter (1964) drew the same conclusion. However, because small differences may occur, the usual method of sampling leaves by compositing material from both sides of the leaf midrib is probably a reasonable precaution.

Considerable plant to plant variation in leaf nutrients occurred even for plants receiving the same fertilizer treatments. The coefficient of variation for leaf N was 7.45%. Twyford and Coulter (1962) found plant to plant variation in leaf N, K, and P to be high also. This suggests that when banana leaf analysis is used as a guide to determine fertilizer rates in commercial fields, a composite of samples from several plants should be used. For example, a composite of 4 samples is required to determine mean leaf N with confidence limits of $\pm$ 0.2% N. This is not to be construed to mean that compositing dissimilar material is the best procedure for experimental work. In that case variability should be isolated so that a wide range of composition can be correlated with yields. For this purpose the continuous function design utilizing individual mats as experimental units is well suited.

Rate of Plant Growth

The discussion which follows considers only the first bunch of bananas produced by each mat. First bunch data have been tabulated for 377 of 384 mats. One first bunch was destroyed by wind and leaf

Table 15. Percent leaf N in left (L) and right (R) lamina halves of No. 3 and bottom leaves of 3 N treatments and treatment K-0. Samples were taken from large plants which had not yet flowered.

Block	Third leaf						Bottom leaf					
	N-0		N-3		N-5		N-0		N-3		N-5	
	L	R	L	R	L	R	L	R	L	R	L	R
1	1.93	2.04	1.97	2.07	2.66	2.81	1.82	1.85	1.54	1.36	1.74	1.65
2	2.02	2.00	2.11	2.17	2.55	2.52	1.47	1.54	1.50	1.11	1.64	1.68
3	1.89	1.81	2.24	2.27	2.81	2.88	1.44	1.33	1.34	1.32	1.78	1.86
4	1.81	1.76	2.32	2.34	2.04	2.23	1.19	1.06	1.47	1.64	1.12	1.41
$\bar{X}$	1.91	1.90	2.16	2.21	2.51	2.61	1.48	1.44	1.46	1.36	1.57	1.65

samples were not taken in 6 cases.

As was stated in the Materials and Methods section, plant densities were maintained at two levels. While this factor may become important when a mat is producing its second or third bunch of bananas, it was probably of minor importance for the first bunch since sucker plants had not yet developed to provide serious competition. Thus blocks 1 through 4 were considered to be replicates. The same holds for blocks 5 through 8.

The average time required from planting to shooting was 206 days. However, flowering began about 156 days after planting and continued for 250 days. Table 16 gives the mean number of days from planting to shooting for each treatment. The designation P-0 refers to blocks 5 through 8 which received no pre-plant phosphate treatment and the designation P-1 refers to blocks 1 through 4 which received phosphate before planting. Each value in Table 16 is the mean of 3 or 4 replications. Plants which received no phosphate generally flowered earlier than the phosphate fertilized plots. (There was less nutsedge competition for N.) Plants with intermediate N treatments had a tendency to shoot earlier than those in either the low N or high N treatments.

The average amount of time from flowering to first bunch harvest was 133 days. The range was 77 to 164 days. Mean times for the various fertilizer treatments are shown in Table 17. A comparison of Tables 16 and 17 shows that generally those treatments which flowered earlier required longer time to mature fruit. Seasonal effects were probably the most important reason for this. Fruit

Table 16. Mean number of days from planting to flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	206	217	194	204	190	187	175	201	188	199	206	236	193	207
K-1	210	320	202	192	180	208	200	187	190	199	197	222	196	221
K-2	196	248	208	231	199	189	202	204	188	202	206	229	200	217
K-3	199	266	178	216	178	196	206	218	186	196	210	250	193	224
K-4	233	343	182	188	178	205	199	201	182	213	202	241	196	232
K-5	180	208	185	205	180	199	174	215	180	206	194	233	182	211
K-6	192	278	176	189	190	189	200	212	181	217	183	233	187	220
K-7	181	285	225	215	201	189	197	212	183	244	191	222	196	228
$\bar{X}$	200	271	194	205	187	195	194	206	185	209	199	233	193	220
$\bar{X}$	235		200		191		200		197		216		207	

[1/] See Appendix Table 34 for analysis of variance.

Table 17. Mean number of days from flowering to harvest of banana for various N, K and P treatments, Waimanalo Experimental Farm.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	129	117	131	131	144	134	144	139	143	133	132	126	137	130
K-1	124	101	134	130	142	133	143	143	137	139	137	128	136	129
K-2	127	110	128	117	131	133	131	132	140	133	135	126	132	125
K-3	131	108	135	125	144	134	136	137	145	136	139	126	138	128
K-4	118	101	143	134	141	130	142	127	144	133	146	124	139	125
K-5	139	127	140	126	144	132	143	124	147	132	141	127	142	128
K-6	130	80	143	132	142	138	134	128	145	126	141	139	139	124
K-7	138	103	130	126	137	136	133	129	146	123	144	130	138	124
$\bar{X}$	129	106	135	128	141	134	138	132	143	132	139	128	138	127
$\bar{X}$	118		132		138		135		138		134		133	

[1/] See Appendix Table 34 for analysis of variance.

development in the early flowering plants began in late December, during the season of short days and cool, cloudy weather (Table 6). Plants which flowered later began fruit maturation when temperatures and day length were more favorable.

Considering all mats, the number of days from planting to first bunch harvest ranged from 310 to 634 and the average was 339. Mean time for each treatment is presented in Table 18. In general more time was needed for producing fruit in the P-1 blocks. Plants receiving intermediate N treatments required less time to produce the first bunch.

First Bunch Yields

First bunch weights ranged from 28 to 75 pounds. Mean weight was 52 pounds. Note from Table 19 that bunches from the N-0 and N-1 treatments weighed least in the blocks where P was added. A thick growth of nutsedge developed where P had been applied. Phosphate may have stimulated growth of the nutsedge or perhaps it affected the efficiency of the Eptam. Heavy nutsedge infestation may also have been associated with more soil K which was measured in blocks 1 to 4 or, as seems more likely, it may have been related to past cropping practices. In any case, nutsedge competition and low nitrification rates caused N deficiency which resulted in reduction of growth and bunch weights. Higher rates of N overcame this competitive effect. Nutsedge competition was probably also an important cause of the delayed flowering which occurred in blocks with the P-1 treatment (Table 16). Bunch weights of this first harvest were not highly correlated to K treatments.

Table 18. Mean number of days from planting to harvest of banana for various N, K and P treatments, Waimanalo Experimental Farm.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	335	334	325	335	334	321	319	340	331	332	338	362	330	337
K-1	334	421	336	322	322	341	343	330	327	338	334	350	333	350
K-2	323	358	336	348	330	322	333	336	328	335	341	355	332	342
K-3	330	374	313	341	322	330	342	355	331	332	349	376	331	351
K-4	351	444	325	322	319	335	341	328	326	346	348	365	335	357
K-5	319	335	325	331	324	331	317	339	327	338	335	360	324	339
K-6	322	358	319	321	332	327	334	340	326	343	324	372	326	343
K-7	319	388	355	341	338	325	330	341	329	367	335	352	334	352
$\bar{X}$	329	376	329	333	328	329	332	339	328	341	338	361	331	346
$\bar{X}$	353		331		329		336		335		350		339	

[1/] See Appendix Table 34 for analysis of variance.

Table 19. Mean bunch weight of banana in pounds for various N, K and P treatments, Waimanalo Experimental Farm. First bunch production, 1972.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	45.7	38.7	50.5	49.3	49.2	54.3	51.0	53.7	53.0	52.0	53.5	59.2	50.5	57.2
K-1	54.5	46.0	54.5	46.7	49.7	53.7	52.2	55.0	53.5	51.7	56.2	52.0	53.4	50.8
K-2	53.5	40.0	55.0	52.7	56.5	51.0	55.7	51.0	54.2	49.0	54.7	54.0	54.9	49.6
K-3	54.5	42.0	49.5	45.5	53.0	54.5	57.0	57.2	53.0	52.2	57.5	62.0	54.1	52.2
K-4	60.7	44.3	55.0	44.5	50.2	54.5	54.5	55.2	55.7	57.0	51.7	58.5	54.6	52.3
K-5	50.2	38.7	55.3	48.7	53.7	56.7	52.0	53.2	52.2	50.7	53.5	54.7	52.8	50.4
K-6	53.7	37.0	52.5	46.5	49.5	56.7	53.7	55.7	49.0	54.0	50.2	53.2	51.4	50.5
K-7	55.7	46.2	60.5	48.5	58.2	52.2	54.2	53.0	52.7	60.0	47.7	52.0	54.8	52.0
$\bar{X}$	53.6	41.6	54.1	47.8	52.5	54.2	53.8	54.2	52.9	53.3	53.1	55.7	53.3	51.1
$\bar{X}$	47.6		51.0		53.4		54.0		53.1		54.4		52.2	

[1/] See Appendix Table 34 for analysis of variance.

A major advantage of crop production in the tropics is year-round growth. Since land can be used every day of the year, it is important to get large yields per crop, and also to produce crops as quickly as possible. For this reason it is more informative to express yield data in terms of production per area per day rather than in terms of production per area per crop. This method of presenting data has been used in a study of sorghum production in Hawaii (Plucknett and Younge, 1963; Plucknett et al., 1971). The usual method of presenting banana yields is bunch weight. Since the amount of time necessary to produce a bunch is important also, yields will be considered in terms of pounds per acre per day in the discussion which follows. Recently, Warner et al. (1973) used this method to present banana data.

All first bunch yields were expressed in pounds per acre per day by converting bunch weight to pounds per acre and dividing by days from planting to harvest. Yields ranged from 22 to 60 pounds per acre per day. The mean was 45 pounds per acre per day. Table 20 gives mean yields for each treatment. For treatment P-1 yields in pounds per acre per day increased to a maximum at intermediate N treatments and then decreased. Table 19 suggests that the corresponding bunch weights increased continuously with N treatment. Intermediate N levels required less time to produce the first bunch (Table 18). The bigger bunches at high N treatments were more than offset by the increased time necessary to produce them.

Relation Between Yield and Leaf Nutrients

Leaf N concentrations at flowering are summarized in Table 21. As expected, leaf N increased as more N fertilizer was applied.

Table 20. Mean yield of banana in pounds per acre per day for various N, K and P treatments, Waimanalo Experimental Farm.
First bunch production, 1972.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	39.6	33.6	45.1	42.6	42.7	49.0	46.4	45.8	46.4	45.5	45.9	47.4	44.3	44.0
K-1	47.4	31.7	47.0	42.0	44.8	45.6	44.1	48.4	47.5	44.4	48.8	43.0	46.6	42.5
K-2	48.0	32.4	47.5	43.9	49.7	46.0	48.5	44.0	48.0	42.4	46.5	44.1	48.0	42.1
K-3	47.9	32.6	45.9	38.8	47.7	47.8	48.4	46.6	46.5	45.5	47.9	47.9	47.4	43.2
K-4	50.1	29.0	49.1	38.7	45.7	47.2	46.4	48.8	49.6	47.8	43.1	46.5	47.3	43.0
K-5	45.6	33.6	49.4	42.6	48.2	49.6	47.6	45.5	46.3	43.5	46.4	44.0	47.2	43.1
K-6	48.4	30.0	47.8	42.0	43.4	50.2	46.6	47.5	43.6	45.6	44.8	41.5	45.8	42.8
K-7	50.6	34.5	49.4	41.3	49.9	46.5	47.6	45.1	46.5	47.4	41.3	42.9	47.5	42.9
$\bar{X}$	47.2	32.9	47.6	41.5	46.5	47.7	46.9	46.5	46.8	45.3	45.6	44.7	46.8	43.0
$\bar{X}$	40.1		44.6		47.1		46.7		46.1		45.2		44.9	

[1/] See Appendix Table 34 for analysis of variance.

Table 21. Mean nitrogen content (%) of third leaf of banana at flowering for various N, K and P treatments, Waimanalo Experimental Farm. First bunch production, 1972.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	2.55	2.43	2.87	2.67	3.05	3.07	3.03	2.97	2.90	2.85	2.80	3.00	2.87	2.83
K-1	2.70	2.02	2.75	2.65	3.07	2.67	2.95	3.07	3.05	3.02	2.92	3.00	2.91	2.74
K-2	2.67	2.50	2.95	2.37	3.05	2.92	2.97	2.80	2.82	3.05	3.00	3.02	2.91	2.78
K-3	2.77	2.20	2.80	2.53	2.97	3.00	3.15	2.70	3.05	2.90	3.12	2.92	2.98	2.71
K-4	2.50	1.97	2.80	2.55	2.95	2.70	3.05	2.87	3.12	2.87	3.00	2.97	2.90	2.65
K-5	3.02	2.47	2.72	2.70	2.95	2.67	2.92	2.80	2.97	2.97	3.12	2.82	2.95	2.74
K-6	2.57	2.20	2.87	2.90	2.92	2.95	2.90	2.80	3.00	2.85	3.02	3.00	2.88	2.78
K-7	2.70	2.25	2.85	2.57	2.72	2.87	2.87	2.70	3.07	2.75	3.02	2.80	2.87	2.66
$\bar{X}$	2.68	2.25	2.83	2.62	2.96	2.86	2.98	2.84	3.00	2.91	3.00	2.94	2.91	2.74
$\bar{X}$	2.47		2.73		2.91		2.91		2.96		2.97		2.83	

[1/] See Appendix Table 34 for analysis of variance.

According to the design of the experiment mean leaf N of the control plants (N-3, K-4) should approximate the assumed critical level of 2.6%. The values shown in Table 21 are higher than this. The high N treatments during the first 5 months apparently were excessive (see Table 9). Moreover, in blocks with treatment P-0 leaf N was normal even when no N was applied (N-0). Nitrate nitrogen production by the soil and NO_3-N in the soil at planting must have been sufficient to maintain near adequate leaf N. Since producing their first bunch, the mats which received little or no N have become increasingly N deficient. Soil N is being taken up continuously by the bananas, but NH_4 and NO_3 production probably has decreased with time since there has been no cultivation to stimulate microorganism activity.

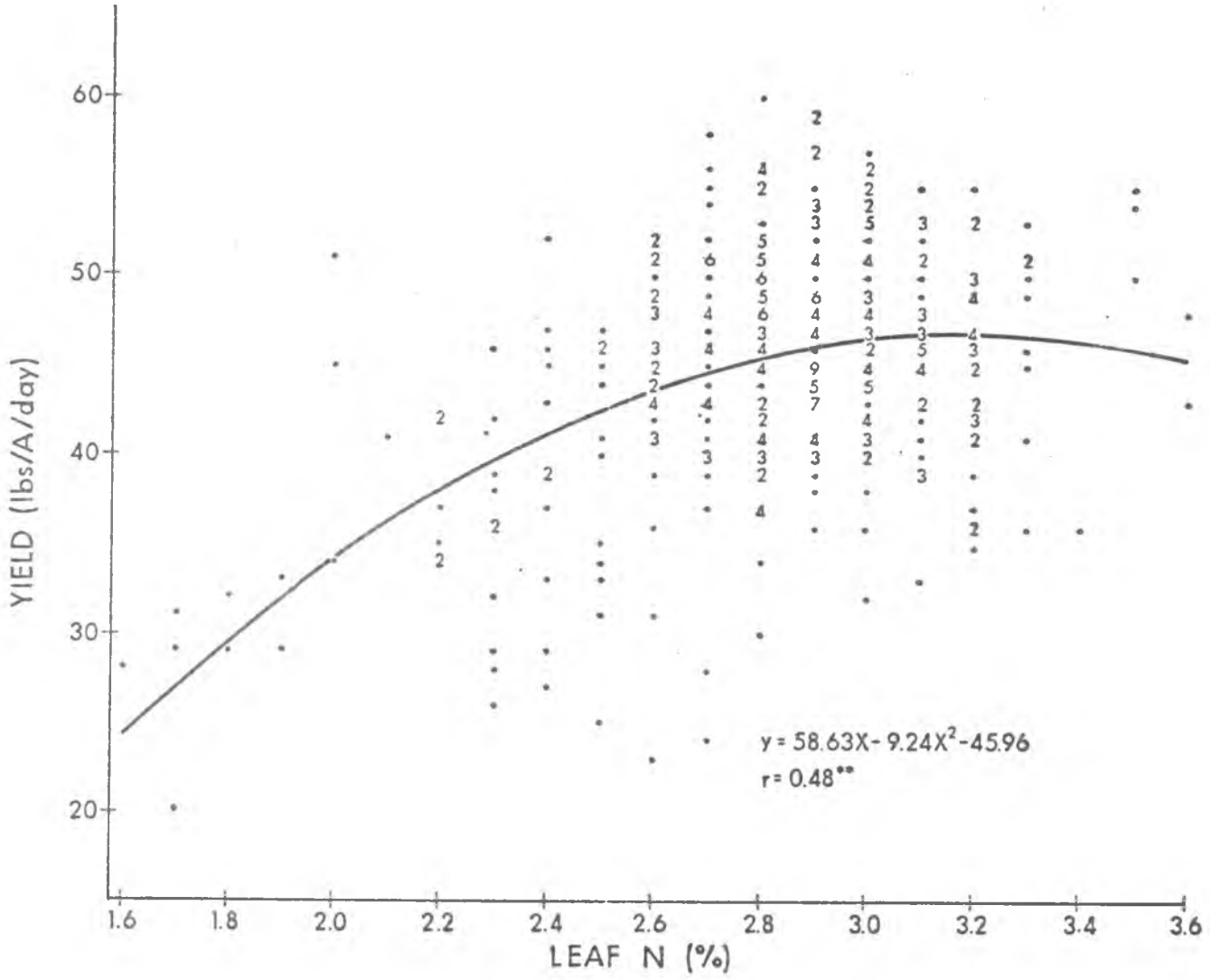
Leaf N was generally lower in blocks which had the pre-plant phosphate treatment (P-1). There was visual evidence of N deficiency at low N treatment levels in these blocks. The main reason for this probably was nutsedge competition. When N is deficient there is a stunting of growth resulting in decreased rate of leaf production and in reduced size of the leaves developed. Since N is translocated to younger leaves, old leaves are a pale yellow-green (Murray, 1959). These symptoms are apparent in Figure 8, which shows plants in block 1 with treatments N-0 through N-5 all with treatment K-7. When N is deficient, leaf petioles tend to be short, thin and compressed (Murray, 1959) and their margins tend to be pink. Such symptoms are evident in Figure 9 for the plant with treatment (N-0, K-4) in block 3.

In Figure 10 yields in pounds per acre per day are plotted against leaf N at flowering. The critical level as defined here is the

Figure 8. Banana plants in block 1 with treatments N-0 to N-6 (left to right) all with treatment K-7. N deficient plants are smaller and leaves are more yellow-green than the others.

Figure 9. Petioles of banana plant in block 3 with treatments N-0 and K-4. The pink borders are evidence of N deficiency.

Figure 10. The relationship between N content of third leaf lamina tissue sampled at flowering and first bunch banana yield.


YIELD (lbs/A/day)
60
50
40
30
20
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
LEAF N (%)
y = 58.63X - 9.24X² - 45.96
r = 0.48**

concentration of a nutrient in No. 3 leaf at flowering which is associated with 95% of the maximum yield attainable under the prevailing conditions. Maximum yield was about 47.1 pounds per acre per day at 3.17% N. Ninety-five percent of the maximum was obtained at about 2.67% N. Confidence limits at the 5% level of significance are ± 1.25% N. This estimate of the critical N level is slightly higher than usually reported as being adequate (Hewitt, 1955; Bidner-Barhava and Ravikovitch, 1958; Murray, 1960).

Leaf N in excess of 3.17% was associated with decreased yields. When an analysis was made of the variance of bunch weight with leaf N, the regression curve (not shown) increased throughout the range of observed leaf N. The data presented in Tables 16, 18, and 21 shows that high leaf N was associated with delayed shooting and thus a longer time from planting to harvest. While bigger bunches were associated with high leaf N, it took a longer time to produce them. Therefore, the yield in pounds per acre per day decreased at high levels of leaf N. A possible explanation for delayed shooting and slower plant growth observed at high levels of leaf N is S deficiency resulting in a high N:S ratio. Sulfur deficiency is suspected when leaf S is below 0.2% in bananas of the Windward Islands (Messing, 1971). Sulfur in the 8 control plants sampled April 26, 1972 ranged from 0.13% to 0.20% (mean 0.15%). All plants were fertilized with elemental sulfur (0.5 lbs. of wettable sulfur per plant) with the result that sulfur levels increased. On September 26, 1972 mean leaf S was 0.19%.

The correlation between yield in pounds per acre per day and leaf N ($r=0.48^{**}$) was much higher than between bunch weight and leaf N

($r = 0.19^{**}$). The advantage of using pounds per acre per day instead of bunch weight was also found in the cases of leaf K ($r = 0.24^{**}$ vs. $r = 0.07$) and leaf P ($r = -0.52^{**}$ vs. $r = -0.28^{**}$).

First bunch yield and critical level were both affected by seasonal influences during the period of fruit development. In Figure 11 separate regression curves are shown for early, intermediate and late flowering plants. During the first fifty days from the time the first plant flowered (December 18, 1971 to January 31, 1972), 235 plants flowered. Ninety plants flowered during the next 50 day period (February 1 to March 22) and 52 flowered after that time. Estimated critical levels for the three periods were 2.58%, 3.82%, and 2.93%, respectively. A possible explanation for the above follows. The first group flowered during the winter when low sunlight intensity caused inadequate carbohydrate production. When N was abundant there was an unfavorable carbohydrate : N balance. The carbohydrate shortage slowed down fruit production and yields in pounds per acre per day decreased with excessive leaf N. The second and third groups flowered during spring and summer. Yields increased with leaf N since carbohydrate production was not such an overriding problem.

While mean bunch weight increased with time from planting to flowering (51.5, 53.0, and 54.9 pounds), mean yield in pounds per acre per day decreased (46.5, 44.4, and 39.3). The reason for this is that total time from planting to harvest increased with lateness to flower.

According to the design of the experiment, leaf K for control plants (N-3, K-4) at flowering should be about 3.3% and leaf K for other K treatments should range above and below this level. Table 22 shows that

Figure 11. The relationship between N content of third leaf lamina tissue sampled at flowering and first bunch yield for early, intermediate and late flowering plants.

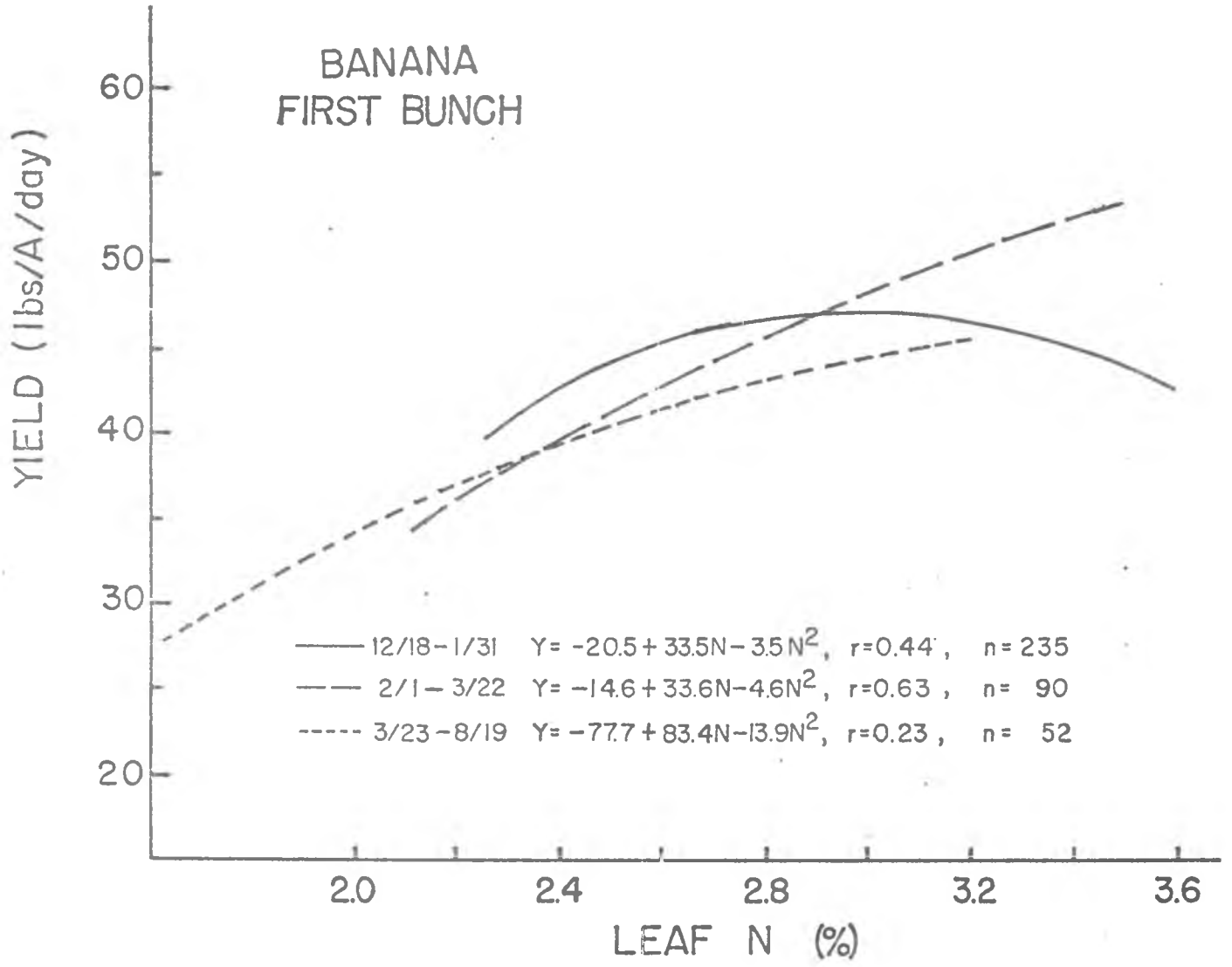

BANANA
FIRST BUNCH
YIELD (lbs/A/day)
60
50
40
30
20
2.0
2.4
2.8
3.2
3.6
LEAF N (%)
12/18-1/31 Y= -20.5+33.5N-3.5N², r=0.44, n=235
2/1-3/22 Y= -14.6+33.6N-4.6N², r=0.63, n= 90
3/23-8/19 Y= -77.7+83.4N-13.9N², r=0.23, n= 52

Table 22. Mean potassium content (%) of third leaf of banana at flowering for various N, K and P treatments, Waimanalo Experimental Farm. First bunch production, 1972.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	5.13	4.70	4.63	5.09	4.62	4.72	4.19	4.66	4.40	4.47	4.98	4.22	4.66	4.64
K-1	4.50	4.21	5.24	4.59	4.17	4.95	4.39	4.49	4.96	4.49	4.58	4.40	4.64	4.52
K-2	4.94	4.50	4.49	4.86	4.58	4.85	4.75	4.65	4.38	4.39	4.87	4.18	4.67	4.57
K-3	4.84	4.23	4.82	4.15	3.85	4.82	4.58	3.97	3.99	4.60	4.60	4.12	4.45	4.31
K-4	4.30	3.46	4.68	4.42	4.61	4.58	4.43	4.70	4.58	4.34	4.88	4.30	4.58	4.30
K-5	4.43	4.32	5.53	4.38	5.18	4.39	4.75	4.72	4.68	4.59	4.78	4.62	4.89	4.50
K-6	5.50	4.00	5.39	4.26	4.99	3.88	4.50	4.60	4.87	4.44	4.54	4.33	4.96	4.25
K-7	5.07	4.42	4.49	4.53	4.93	4.19	4.94	5.33	4.28	4.44	4.49	4.38	4.70	4.55
$\bar{X}$	4.84	4.23	4.91	4.53	4.62	4.55	4.57	4.64	4.52	4.47	4.71	4.32	4.69	4.46
$\bar{X}$	4.54		4.72		4.59		4.61		4.50		4.52		4.58	

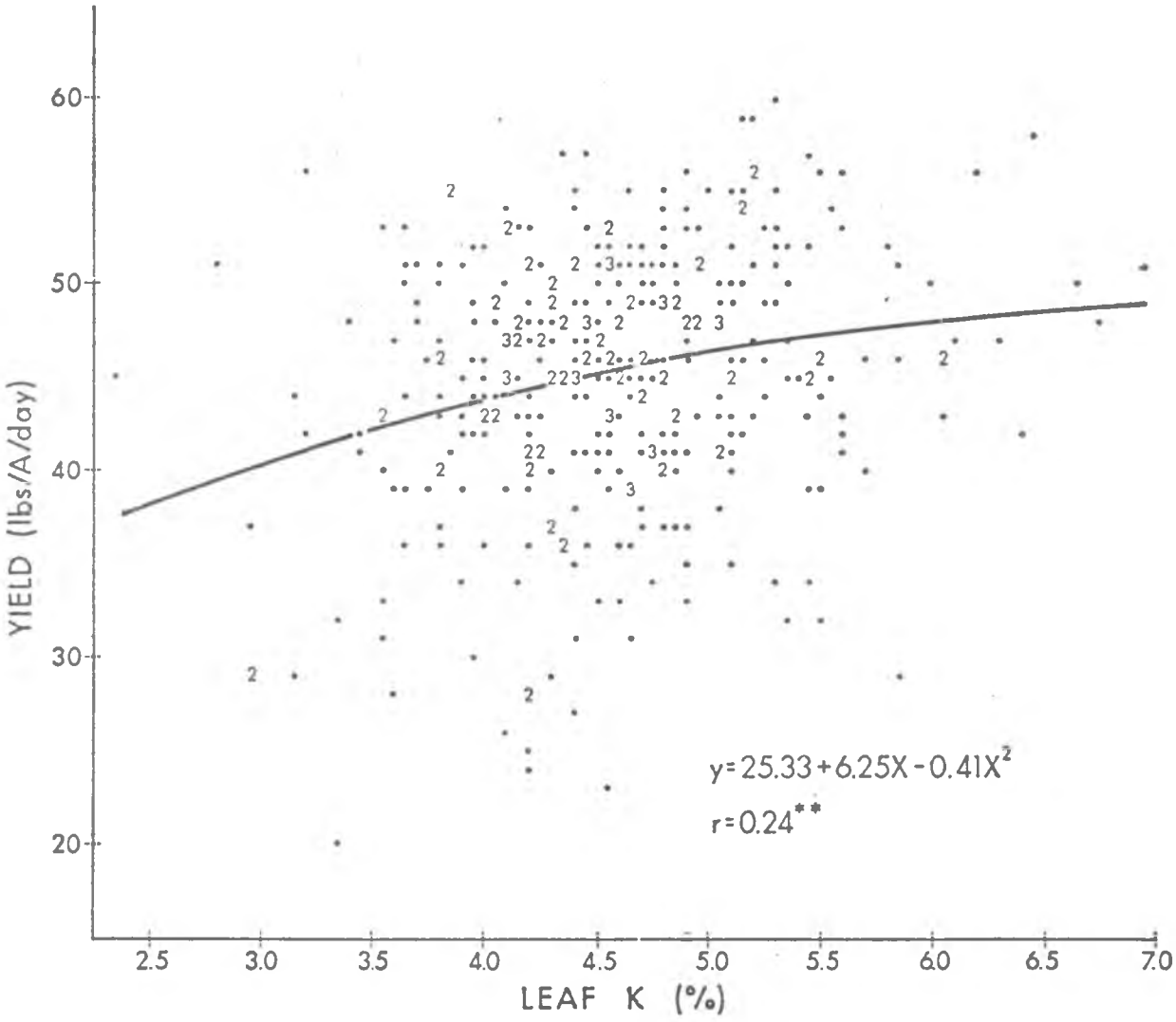
[1/] See Appendix Table 34 for analysis of variance.

mean leaf K for every treatment was above 3.3% and that leaf K varied little with K treatment. There are probably several reasons for these results. Since leaf K was high even for treatments with no K addition (K-0), the K initially in the soil was adequate for initial production. Apparently, the high K treatments during the first 5 months were excessive (see Table 10). The K stored in the corm at planting may also have been a factor. Considerable growth is possible from the nutrients stored in the corm except in the case of N (Murray, 1960; De Geus, 1967). Since the time of first bunch production, soil K has decreased in mats with low K treatments. However, more recent results not included in this thesis indicate that K fertilization is having little influence of K content of plants. The reason(s) for this are not clear at this time.

In general, leaf K was lower in the blocks which received phosphate before planting (P-1). Soil data demonstrate that there was more K available in these blocks (Figure 4). Nitrogen deficiency was more pronounced in these blocks. This resulted in generally poorer growth and smaller uptake of K. This does not explain why leaf K was also lower at high N treatments where there was no N deficiency. It may be that nutsedge competes for K as well as N. Perhaps excess soil phosphate depressed leaf K and N. Such a depressing effect was reported by Hewitt (1955).

First bunch yield was plotted against leaf K in Figure 12. From the regression curve the critical level was calculated to be about 5% K. Previous studies elsewhere have indicated that this level is about 3.3% K for leaf No. 3 (Hewitt and Osborne, 1962; Bhangoo et al.,

Figure 12. The relationship between K content of third leaf lamina tissue sampled at flowering and first bunch banana yield.


YIELD (lbs/A/day)
60
50
40
30
20
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
LEAF K (%)
y=25.33+6.25X-0.41X²
r=0.24**

1962; Hagin et al., 1964). Ho (1969) determined the critical level for Giant Cavendish to be 4.75% K, but this was for the third leaf at 6 months rather than flowering. The extraordinarily high value obtained here probably results from uncertainty associated with variability in the data. Better curves can be expected as soil K becomes depleted as a function of time.

The experiment was not primarily designed to study the relation between banana yield and leaf P. Only two P treatment levels were used. It turned out that the amount of P in the soil at planting was sufficient to attain super adequate levels of leaf P. Table 23 shows that even treatment P-0 was associated with 0.21% to 0.22% leaf P. Adequacy at 0.18% has been reported (Murray, 1960; Hewitt and Osborne, 1962). Where N was deficient (low N treatments, P-1 blocks) leaf P was very high. At higher N treatment levels there was little difference between the P-0 and P-1 blocks. One explanation for this is that leaf P was decreased by a dilution effect due to rapid growth at the high N treatments. When N is deficient, slow growth causes P to accumulate in leaves (Murray, 1960). It is also possible that there was competition for uptake by the plants between NO_3 and H_2PO_4. When NO_3 was very low more H_2PO_4 was taken up.

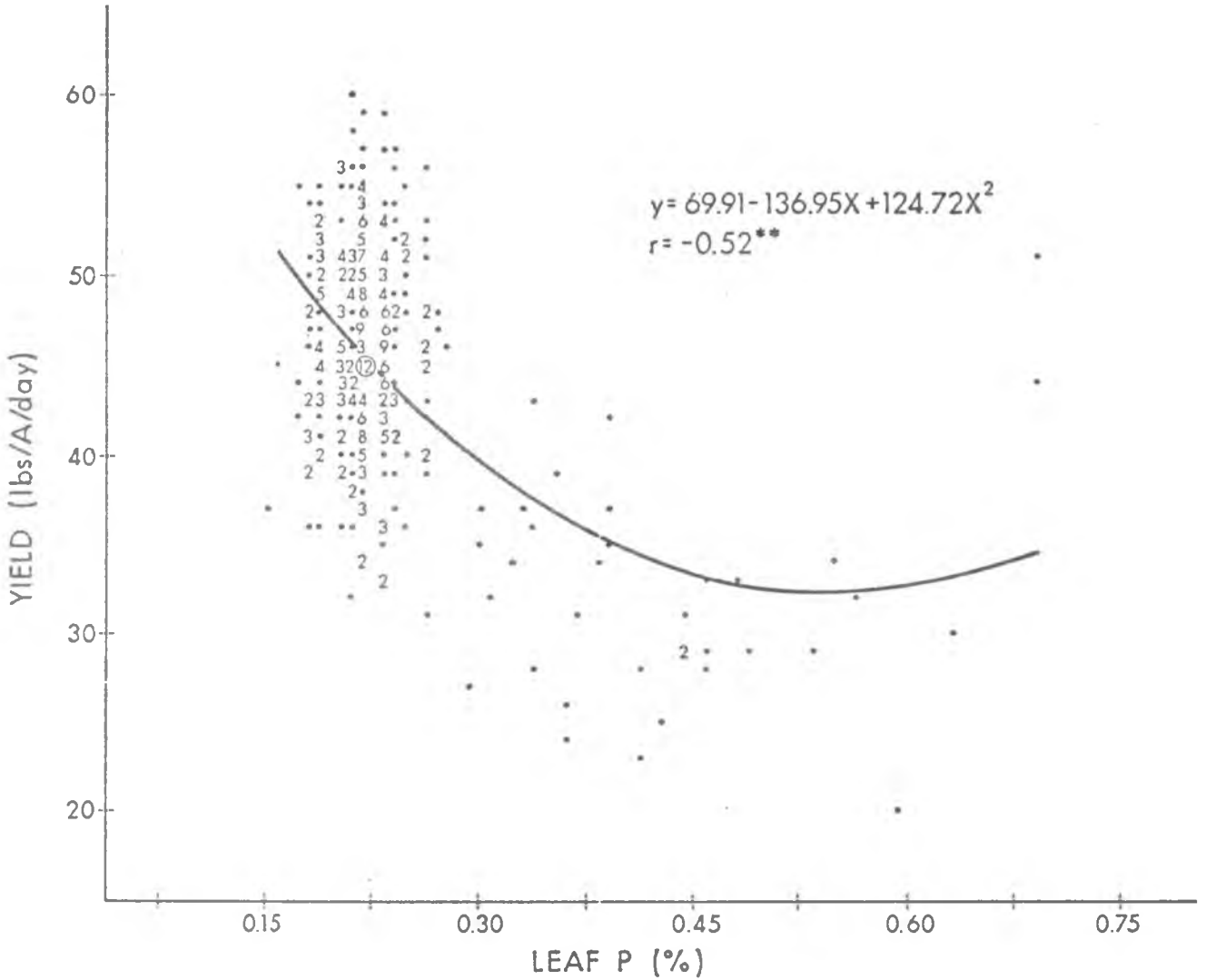
In Figure 13, first bunch yield was plotted against leaf P. With only 2 P treatments, it is not surprising that most leaf P values are found within a narrow range. The few points with high P and low yield were explained earlier as resulting from P accumulation in cases of N deficiency resulting in poor growth. These points cause the negative correlation. A critical level could not be determined from the data

Table 23. Mean phosphorus content (%) of third leaf of banana at flowering for various N, K and P treatments, Waimanalo Experimental Farm. First bunch production, 1972.[1/]

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	.24	.31	.22	.24	.21	.23	.21	.22	.20	.22	.22	.23	.22	.24
K-1	.21	.43	.21	.25	.21	.22	.22	.21	.21	.23	.23	.23	.21	.26
K-2	.20	.47	.21	.31	.21	.22	.22	.21	.21	.22	.23	.22	.21	.27
K-3	.23	.41	.19	.27	.19	.22	.22	.20	.22	.22	.21	.21	.21	.25
K-4	.24	.48	.20	.20	.21	.22	.22	.23	.21	.23	.22	.21	.22	.26
K-5	.22	.30	.34	.23	.21	.21	.22	.22	.21	.21	.23	.23	.24	.23
K-6	.22	.40	.21	.23	.21	.33	.21	.21	.21	.23	.20	.20	.21	.27
K-7	.22	.36	.22	.27	.23	.22	.22	.22	.19	.23	.23	.23	.22	.25
$\bar{X}$	.22	.39	.22	.25	.21	.23	.22	.21	.21	.22	.22	.22	.22	.25
$\bar{X}$	.31		.24		.22		.22		.22		.22		.24	

[1/] See Appendix Table 34 for analysis of variance.

Figure 13. The relationship between P content of third leaf lamina tissue sampled at flowering and first bunch banana yield.


y= 69.91-136.95X+124.72X²
r= -0.52**
YIELD (lbs/A/day)
60
50
40
30
20
0.15
0.30
0.45
0.60
0.75
LEAF P (%)

because almost all leaf P concentrations were above the assumed critical level of 0.18%.

Effect of Fertilization on Yield and Leaf Nutrients

The rate of N applied to each mat from planting to harvest was calculated in pounds per acre per year. In Figure 14 these values were plotted against yield in pounds per acre per day. The regression curve indicates that maximum yield was obtained when N was applied at 360 pounds per acre per year. However, 95% of the maximum was obtained with about 130 pounds per acre per year. Since there were about 290 mats per acre, this is equivalent to 0.45 pounds (204 g) per mat per year.

In Figure 15 the rate of N applied during the period from planting to flowering was plotted against leaf N at flowering. From the regression curve, N was required at the rate of 460 pounds per acre per year to produce 3.00% leaf N. The critical level (2.67%) was obtained with only 75 pounds N per acre per year.

Regression analyses were also made of the relations between yield and applied K and between leaf K and applied K. These manipulations indicate little response to K treatments in either case.

Leaf Concentrations of Ca, Mg and Microelements

The studies reported in this thesis involved only N, K and P as variables. Mean third leaf concentrations at flowering of several other elements are presented in Appendix Tables 24 to 33 for various N, K and P treatments. Calcium concentrations ranged from 0.49 to 0.61% and Mg concentrations ranged from 0.45 to 0.52%. Little work has been done on the requirements for these nutrients for banana, but one report suggests

Figure 14. The relationship between N applied from planting to harvest and first bunch banana yield.

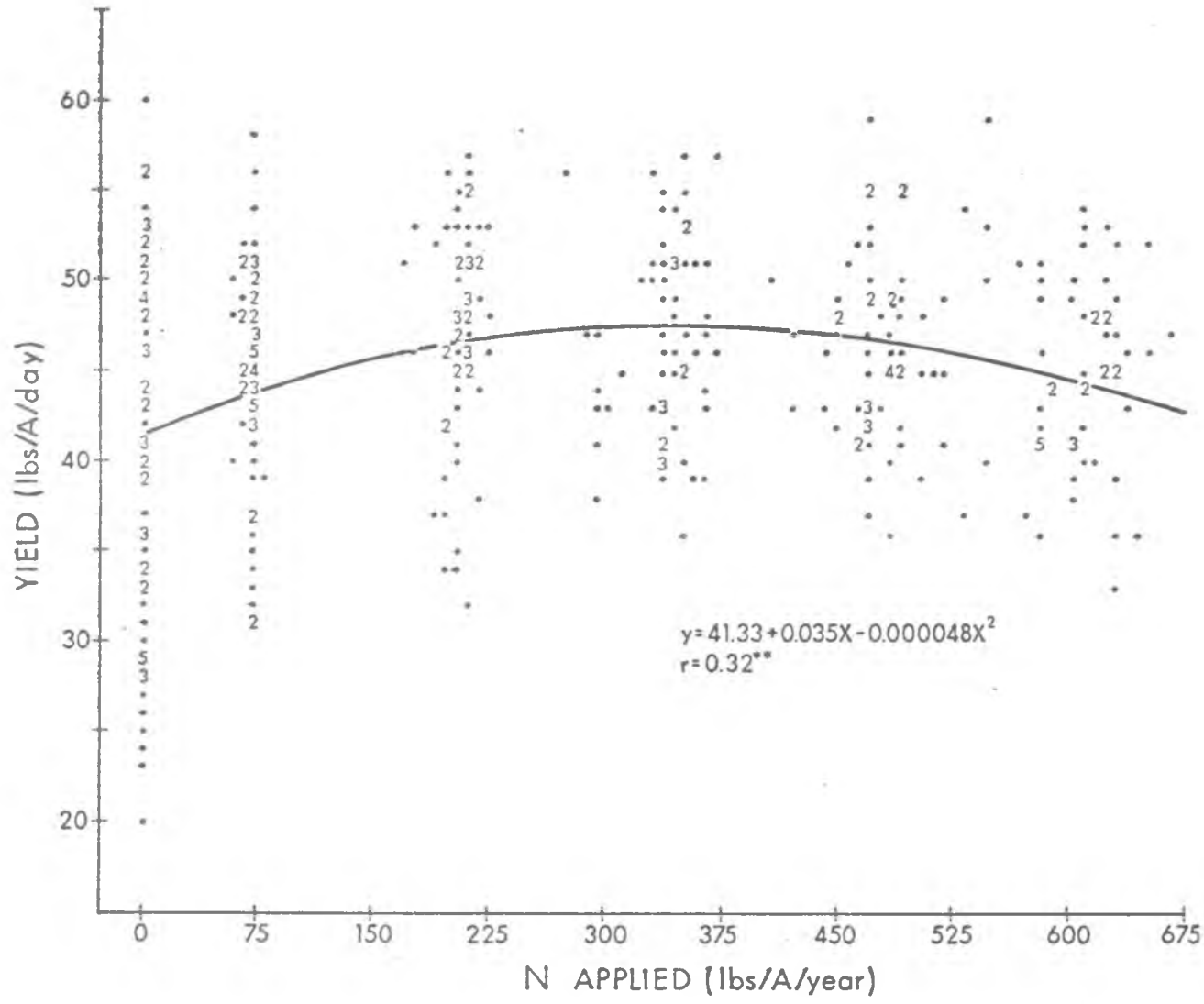
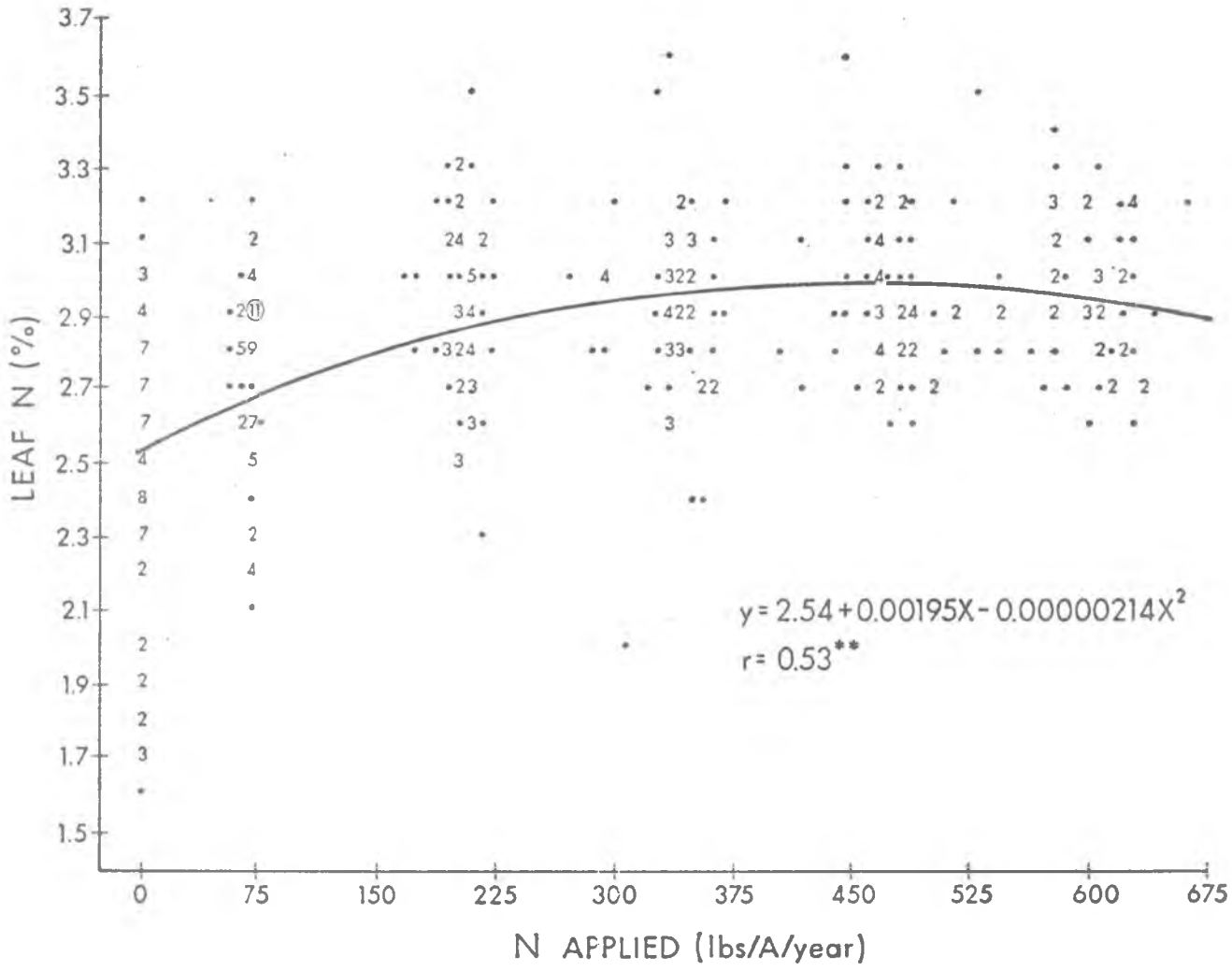

YIELD (lbs/A/day)
60
50
40
30
20
0
75
150
225
300
375
450
525
600
675
N APPLIED (lbs/A/year)
y=41.33+0.035X-0.000048X²
r=0.32**

Figure 15. The relationship between N applied from planting to flowering and leaf N of third leaf lamina tissue sampled at flowering. Only first banana bunch data are included.


LEAF N (%)
3.7
3.5
3.3
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
0
75
150
225
300
375
450
525
600
675
N APPLIED (lbs/A/year)
y = 2.54 + 0.00195X - 0.00000214X²
r = 0.53**

that 1.0% Ca and 0.36% Mg are adequate (Murray, 1959). By these standards leaf concentrations of Ca appear low, although soil pH and soil Ca were in a satisfactory range. A possible explanation is that Ca was decreased by competitive effects of K and Mg. (Exchangeable Ca and Mg were about 10 meq/100g soil each.) Chalker and Turner (1969) reported severe Mg deficiency symptoms when leaves contained less than 0.2% Mg. A systematic study to estimate critical levels for Ca and Mg should be useful. Very little work has been done on microelement concentrations in, or requirements of, banana plants. An expansion of research in this area should be useful also. Although nothing can be said here about the adequacy or toxicities of microelements, tissue analysis data accumulated in the course of this study are presented in the Appendix so they can be compared with future work. For convenience, mean third leaf concentrations for treatments P-0 and P-1 are summarized below:

	P-0	P-1
Mn (ppm)	176	290
Fe (ppm)	92	79
B (ppm)	15	13
Cu (ppm)	12	11
Zn (ppm)	15	15
Al (ppm)	56	41
Mo (ppm)	3	3
Na (ppm)	198	199

In Trinidad on "normally growing" Robusta bananas, mean fourth leaf concentrations were Mn 830 ppm, Fe 115 ppm, B 100 ppm, Cu 19 ppm, Zn 24 ppm and Al 86 ppm (Twyford, 1967). Gabuin (1969) reported that

mean third leaf concentrations for Gros Michel in Hawaii were Mn 184 ppm, Zn 39 ppm, Al 30 ppm, S 0.38% and Si 0.18%. Dwarf Cavendish plants were visibly deficient when leaf Mn was less than 10 ppm (Jordine, 1962). Leaf Na at 700 ppm was normal for Dwarf Cavendish (Bidner-Barhava and Ravikovitch, 1958).

By standards established for many crops, the Zn levels reported here are low. Also the values reported here are low compared with data from Twyford (1967) and Gabuin (1969). These data suggest that studies on Zn nutrition of banana should be worthwhile at the Waimanalo location.

Although the boron levels are very much lower than those reported by Twyford (1967), there is no reason to suspect B deficiency. Monocots generally have lower B requirements than dicots and leaf B values reported here are normal when compared to other monocots such as corn. Besides, the nature of the soil (clay) and the proximity of the site to the sea seems to preclude a B problem at this location.

V. SUMMARY AND CONCLUSIONS

A study of Giant Cavendish bananas in Hawaii was made to determine relations between third leaf nutrient concentrations at flowering and yield. Four blocks of 48 plants each received a pre-plant phosphate treatment while 4 other blocks received no P. Nitrogen and K were varied in each block in a two-way, continuous function design. A control plant from each block receiving intermediate N and K treatments was sampled periodically. Rates and frequency of fertilization were adjusted to keep N of the control plant (third leaf) at 2.6% and K at 3.3%. Nitrogen and K were supplied to other plants in the block in a fixed ratio. Amounts ranged from none to rates considered excessive.

The leaf sampling technique used was checked in a preliminary study of N and K distribution in plants. With an adequate N supply, leaf N was maximum in leaf 2 to leaf 5 and then decreased with leaf number. For deficient N, maximum N was in leaf 1. Leaf K was higher in the youngest leaves than in the oldest leaves, but the rate of decline was small for the first 9 leaves. Leaf N was greatest at the leaf apex and decreased towards the base. Leaf K was most concentrated in the base and decreased towards the apex. Leaf N was essentially the same on both sides of the leaf axis. These results are in general agreement with studies reported in the literature.

The critical level was defined as third leaf concentration of a nutrient at which yield was 95% of maximum attainable under prevailing conditions. Maximum first bunch yield was 47.1 pounds per acre per day at 3.17% N. Ninety-five percent of this maximum was obtained at about 2.67% N which is only slightly more than the concentrations usually reported to be adequate. A decrease in yield was noted when

leaf N exceeded 3.17%. This was attributed to delayed flowering and slower plant growth associated with S deficiency.

Potassium in equilibrated soil solution (0.0025 N Cl) corrected to zero K desorbed was about 0.10 meq/l in blocks which received pre-plant P and about 0.03 meq/l in the other blocks. Since plants showed some response to K fertilization in the former but not in the later blocks, the borderline deficiency level for K in soil solution is probably about 0.10 meq/l. The regression curve suggests a critical leaf K level of about 5.0%. This is considerably higher than most results reported in the literature. It is probably not a reliable estimate since the response curve was almost flat. Most leaves contained more than 3.3% K, the approximate critical level reported by others.

Phosphate adsorption curves for unfertilized soil indicate that P in soil solution was about 0.05 ppm. Since no P deficiency symptoms were apparent, this P concentration in soil solution is probably adequate for bananas. Leaf P concentrations were very high and thus a critical level could not be estimated.

Mean third leaf concentrations of Ca and Mg were 0.57 and 0.49%, respectively. Calcium concentrations of about 1.0% and Mg concentrations of about 0.36% have been reported by others to be adequate.

On the basis of the study reported in this thesis, the following conclusions seem justified.

1. The continuous function design works well for banana nutrition experiments.

2. The best estimate is that maximum yield is attained when the third leaf N concentration at flowering is about 3.17%. Ninety-five

percent of this maximum is obtained at about 2.7% N.

3. While bunch weight increases with leaf N, a longer time is necessary to produce the bunches at high leaf N resulting in lower yield per acre per day.

4. Infestation with weeds such as nutsedge can seriously effect leaf N concentrations and perhaps K concentrations as well.

5. Yield in pounds per acre per day is better correlated with leaf nutrients than is bunch weight.

6. While bunches produced by early flowering plants weigh less, their yields expressed in pounds per acre per day are larger than for plants which take longer to flower.

7. Any leaf from No. 2 to No. 5 may be chosen for sampling in future nutrition experiments with N and K.

8. Phosphorus in soil solution of 0,05 ppm is adequate for bananas.

9. Borderline K deficiency for banana is associated with an equilibrium concentration of about 0.1 meq/1 K in 0.0025 N Cl.

Appendix Table 24. Mean Ca content (%) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	.56	.40	.63	.50	.58	.61	.58	.62	.57	.55	.45	.67	.56	.56
K-1	.55	.48	.47	.52	.68	.52	.66	.63	.66	.64	.54	.67	.59	.58
K-2	.57	.55	.69	.57	.65	.53	.64	.45	.56	.63	.58	.72	.61	.57
K-3	.53	.49	.56	.54	.66	.61	.72	.63	.65	.57	.62	.60	.62	.57
K-4	.51	.45	.55	.59	.58	.54	.67	.54	.60	.55	.53	.61	.57	.55
K-5	.57	.58	.59	.57	.64	.53	.62	.58	.54	.65	.62	.48	.60	.56
K-6	.50	.55	.53	.74	.63	.64	.55	.53	.55	.58	.60	.64	.56	.61
K-7	.49	.41	.59	.51	.46	.51	.47	.44	.61	.47	.54	.51	.52	.48
$\bar{X}$	.53	.49	.57	.57	.61	.56	.61	.55	.59	.58	.56	.61	.58	.56
$\bar{X}$	.51		.57		.59		.58		.59		.59		.57	

Appendix Table 25. Mean Mg content (%) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	.47	.41	.48	.44	.52	.47	.48	.52	.50	.46	.47	.55	.48	.47
K-1	.51	.41	.43	.47	.56	.48	.56	.49	.51	.47	.49	.55	.51	.48
K-2	.49	.42	.55	.49	.52	.44	.49	.39	.47	.52	.50	.61	.50	.48
K-3	.48	.42	.44	.49	.54	.47	.59	.54	.58	.47	.52	.52	.52	.48
K-4	.49	.47	.43	.46	.46	.42	.54	.47	.50	.53	.47	.50	.48	.47
K-5	.49	.51	.48	.51	.45	.44	.50	.50	.41	.55	.53	.48	.48	.50
K-6	.51	.50	.44	.51	.47	.57	.45	.48	.44	.53	.48	.49	.46	.52
K-7	.47	.43	.54	.48	.46	.47	.42	.41	.47	.49	.45	.50	.47	.46
$\bar{X}$	.49	.45	.47	.49	.50	.47	.50	.47	.48	.50	.49	.52	.49	.48
$\bar{X}$	.47		.48		.49		.49		.49		.51		.49	

Appendix Table 26. Mean Mn content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	150	155	163	162	192	243	201	257	165	280	188	474	176	262
K-1	136	189	131	193	221	382	238	289	163	376	182	415	178	307
K-2	159	177	191	204	216	251	197	227	154	279	212	504	188	274
K-3	153	163	152	277	201	273	265	267	174	246	309	448	209	279
K-4	130	171	130	225	159	303	238	260	185	355	197	387	173	283
K-5	147	224	120	228	170	302	150	506	161	397	166	408	152	344
K-6	122	212	145	311	166	341	215	369	138	346	225	228	168	301
K-7	124	149	197	248	176	255	154	241	181	406	168	349	166	274
$\bar{X}$	140	180	154	231	187	294	207	302	165	336	206	401	176	290
$\bar{X}$	160		193		241		255		251		304		233	

Appendix Table 27. Mean Fe content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	88	79	93	75	88	77	91	79	99	77	84	77	90	77
K-1	82	83	84	86	91	82	94	86	93	77	115	92	93	84
K-2	81	71	149	81	98	74	99	76	88	81	69	96	97	80
K-3	82	74	91	88	99	82	99	82	95	66	108	78	96	78
K-4	85	71	86	89	100	70	87	77	82	80	83	84	87	79
K-5	89	94	91	75	86	84	102	85	82	93	81	74	88	84
K-6	109	74	88	82	98	74	95	81	82	78	92	79	94	78
K-7	97	73	97	90	88	70	80	67	108	78	75	73	91	75
$\bar{X}$	89	77	97	83	93	76	93	79	91	79	88	81	92	79
$\bar{X}$	83		90		85		86		85		85		86	

Appendix Table 28. Mean B content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	13	12	17	13	12	12	13	11	16	15	20	13	15	13
K-1	12	16	16	13	14	16	13	13	19	14	15	13	15	14
K-2	14	12	13	12	12	13	12	15	13	14	13	11	13	13
K-3	14	11	14	12	12	12	11	14	11	9	18	12	13	12
K-4	17	16	11	11	17	15	14	15	16	13	19	12	15	14
K-5	16	12	10	12	13	12	14	12	14	11	18	18	14	13
K-6	15	12	15	8	15	11	16	12	16	16	15	16	15	12
K-7	15	20	16	15	15	13	16	14	17	14	17	15	16	15
$\bar{X}$	14	14	14	12	13	13	14	13	15	13	17	14	15	13
$\bar{X}$	14		13		13		14		14		16		14	

Appendix Table 29. Mean Cu content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	12	14	12	11	11	13	11	11	11	10	10	10	11	11
K-1	17	11	13	11	14	11	14	11	12	12	12	17	13	12
K-2	11	10	10	12	13	12	12	11	10	10	12	12	11	11
K-3	12	11	12	11	11	12	13	11	12	12	12	11	12	11
K-4	11	13	11	10	12	12	12	11	12	12	14	12	12	11
K-5	14	17	12	13	12	10	13	10	12	11	14	11	13	12
K-6	14	13	13	12	12	11	14	10	13	15	13	12	13	12
K-7	12	12	14	12	16	10	12	10	15	12	14	19	14	12
$\bar{X}$	13	13	12	11	12	11	12	10	12	12	12	13	12	11
$\bar{X}$	13		12		12		11		12		13		12	

Appendix Table 30. Mean Zn content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	12	17	16	15	17	18	17	12	14	15	14	16	15	15
K-1	14	18	15	13	16	14	15	17	14	16	14	13	14	15
K-2	13	15	12	14	14	19	14	16	14	13	14	13	13	15
K-3	14	16	15	14	14	19	14	16	15	17	16	16	15	16
K-4	14	16	14	14	16	19	18	16	18	17	14	14	16	16
K-5	18	16	12	15	15	15	13	14	18	12	15	16	15	15
K-6	12	18	16	18	15	15	15	15	16	16	16	17	15	16
K-7	14	15	15	16	15	15	15	15	16	15	21	15	16	15
$\bar{X}$	14	16	14	15	15	17	15	15	16	15	15	15	15	15
$\bar{X}$	15		15		16		15		16		15		15	

Appendix Table 31. Mean Al content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	53	36	63	35	49	41	53	40	58	38	46	34	54	37
K-1	43	44	43	42	54	37	54	51	53	40	81	46	54	43
K-2	48	39	61	39	55	42	63	45	49	41	31	46	51	42
K-3	45	39	58	49	53	48	65	41	50	33	73	31	57	40
K-4	53	31	44	44	65	37	48	43	48	43	53	55	52	42
K-5	62	58	61	35	56	45	67	37	52	47	48	35	58	43
K-6	74	35	56	44	61	36	68	38	54	43	51	45	60	40
K-7	64	31	61	50	59	35	45	33	91	45	48	40	61	39
$\bar{X}$	55	39	56	42	56	40	58	41	57	41	54	41	56	41
$\bar{X}$	47		49		48		50		49		48		49	

Appendix Table 32. Mean Mo content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	3.0	2.7	3.2	2.9	2.9	3.2	3.1	3.0	3.2	2.9	2.7	3.0	3.0	2.9
K-1	2.9	2.8	2.8	3.1	3.2	3.2	3.0	2.9	3.0	3.1	3.1	3.3	3.0	3.1
K-2	2.9	3.0	3.0	3.1	3.0	2.9	2.9	3.1	2.6	3.1	2.3	3.6	2.8	3.1
K-3	3.2	2.8	2.8	3.2	2.9	3.0	3.2	3.2	3.3	3.0	3.1	3.0	3.1	3.0
K-4	3.1	3.1	2.5	2.8	3.0	2.8	3.2	3.0	2.8	3.2	2.9	3.6	2.9	3.1
K-5	3.2	3.2	3.1	3.2	2.7	2.9	3.3	3.2	3.0	2.9	3.2	3.2	3.0	3.1
K-6	3.2	3.1	2.8	3.5	2.9	3.3	3.0	3.0	3.1	3.3	2.9	2.7	3.0	3.1
K-7	2.8	2.8	2.7	3.3	2.9	3.2	2.8	2.7	3.0	3.1	3.2	3.2	2.9	3.0
$\bar{X}$	3.0	2.9	2.8	3.1	2.9	3.0	3.0	3.0	3.0	3.1	3.0	3.2	3.0	3.0
$\bar{X}$	3.0		3.0		3.0		3.0		3.1		3.1		3.0	

Appendix Table 33. Mean Na content (ppm) of third leaf at flowering of banana for various N, K and P treatments, Waimanalo Experimental Farm.

	N-0		N-1		N-2		N-3		N-4		N-5		$\bar{X}$	
	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1	P-0	P-1
K-0	149	143	243	114	186	102	59	169	173	240	175	136	164	151
K-1	166	282	138	269	778	177	114	390	204	126	269	212	278	242
K-2	159	100	155	213	120	63	907	320	125	179	671	172	356	174
K-3	199	89	162	212	138	113	233	177	120	70	99	189	158	142
K-4	201	16	121	216	203	97	100	232	57	157	143	308	137	171
K-5	124	303	178	113	175	199	222	89	77	308	176	737	158	291
K-6	331	63	161	84	221	272	180	780	176	132	135	142	201	245
K-7	159	122	152	338	150	137	87	149	144	202	104	105	133	176
$\bar{X}$	186	140	164	195	246	145	238	288	134	177	221	250	198	199
$\bar{X}$	163		180		196		263		156		236		199	

Appendix Table 34. Analysis of variance of data presented in Tables 16 to 23. Values are mean squares.

Source of variation	df	Days from planting to flowering	Days from flowering to harvest	Days from planting to harvest	Bunch weight (lbs)	Yield (lbs/A/day)	Leaf N (%)	Leaf K (%)	Leaf P (%)
N	5	4284.96**	728.80**	1833.33**	100.27**	117.85**	0.5915**	0.1209	0.0208**
K	7	466.33	48.31*	309.19	14.53	3.45	0.0126	0.1323	0.0003
P	1	17055.88**	2658.61**	6243.60**	123.31**	352.67**	0.7291**	1.4842**	0.0354**
NK	35	414.12	36.65**	245.49	12.32*	3.84	0.0170	0.0739	0.0009
NP	5	2278.24**	119.46**	1375.59**	137.99**	156.66**	0.0782**	0.3169*	0.0175**
KP	7	177.90	35.15	85.30	9.12	7.60	0.0191	0.1375	0.0013
Error	95	234.35	18.59	175.36	7.43	5.60	0.0160	0.1193	0.0009

* Significant at 5% level.

** Significant at 1% level.

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